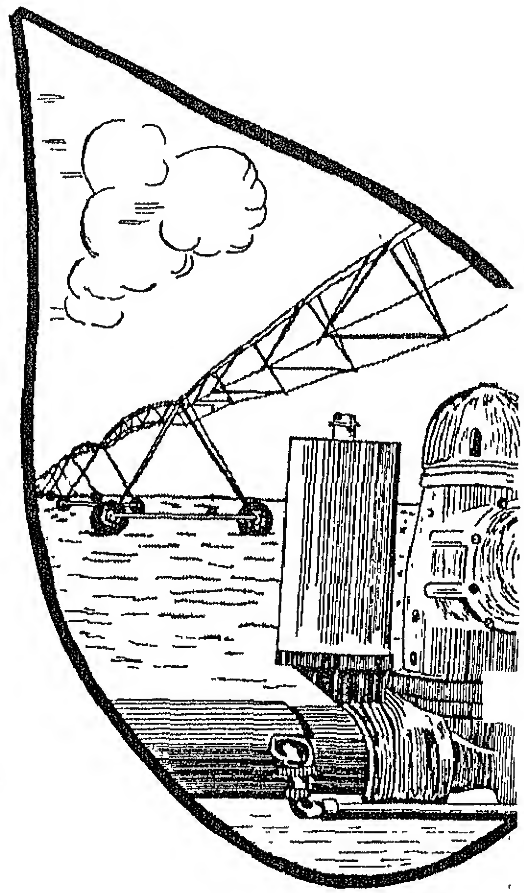
COLORADO IRRIGATION GUIDE



U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
DENVER, COLORADO

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Part 680 - Introduction

Part 680 - Introduction

SUPART A - GENERAL

CO680.1 Purpose and objectives of the guide.

(a) This guide was developed to assist Soil Conservation Service technicians and other planners in Colorado in the desi and management of conservation irrigation syutems for good irrigation water management. It applies to the entire State (Colorado.

(b) This guide is distributed to Soil Conservation Servic Field Offices and is available to others who need this type of information.

(c) Use of the basic data in this guide will assure irrigation systems capable of supplying the amounts of water needed by plants for maximum production during periods of peak consumptive use. Peak use occurs during the warmest period of the growth cycle when the plant's maximum growth occurs. Norm seasonal irrigations do not necessarily require these maximum design irrigation water applications.

(d) Many principles of conservation irrigation are basic both drainage and erosion control. Soil Conservation Service personnel should consider these other needs when developing conservation irrigation plans. Environmental aspects must be considered with respect to water quality, sedimentation and pollution by surface runoff and deep percolation.

(1) This guide may not include data on all soils and crops in certain locations. Users may also find that criteria may not fit certain soils in some locations. It should provid basis for collecting and evaluating data that may be missing a for revising guide material as needed.

(2) This guide is assembled in sections so that revisi can be made as new data becomes available. Users are encourag to report needed additions or changes.

C0680.2 Relationship of irrigation to water quality and pollution.

(a) Since irrigation is a primary user of water in the State, water quality criteria for irrigation becomes more significant. Intensive development in recent years, coupled with the generally short water supply in most western streams, has tended to decrease water quality.

(b) The Federal Water Pollution Control Act provides for the abatement and control of pollution of interstate waters. States are formulating water quality requirements within Federal guidelines. Everyone involved with irrigation should become acquainted with Federal as well as State requirements.

C0680.3 Soils.

(a) Soils information is included in Part 681 of this Guide. This information is taken directly from Soils Resource Information Systems (SRIS) and can be extracted by counties for inclusion in the Guide. In this manner, only the soils found in a particular county need to be in a particular Field Office copy of the guide. The intake families were derived from "ring infiltrometer" data and are useful mainly in border and contour ditch system design. As additional information is obtained from furrow and sprinkler trials the intake families can be updated for this type of irrigation.

(b) Part 681 can be updated almost yearly by the use of a computer that can access the SRIS program.

(c) Special limitations based on drainage or saline-alkaline conditions may have to be made based on on-site investigations by a soil scientist.

C0680.4 Crops.

(a) Part 682 of this Guide contains information on the commonly irrigated crops. Considerations of management, critical irrigation periods, moisture stress periods, and other special irrigation considerations are included for each of these crops.

CO680.5 Water requirements.

(a) The State has been divided into seven climatic zones as evidenced by areas of peak period consumptive use rates for pasture grasses. The boundaries of these areas are shown on the state map, Figure CO680.1, Part 680 of the Guide. Estimated monthly consumptive use by crop and effective precipitation are shown by county in Tables CO683.50(a) through (aa). Net monthly irrigation requirement is the difference between crop consumptive use and effective precipitation. For more precise information, the computer data sheets for each weather station should be consulted.

CO680.6 Irrigation method selection.

(a) Including other possible factors that may enter in, irrigation method selection is largely a function of the crop, soil, slope, and climatic zone. Part 684 of the Guide offers guidelines which may be used in determining the most feasible method or methods of irrigation for a given set of circumstances.

CO680.7 Irrigation methods and design criteria.

(a) Included in Part 685 of the Guide are criteria for design and implementation of the more commonly used methods of irrigation in Colorado.

CO680.8 Farm distribution systems.

Water must be delivered to each part of the farm at the time, rate, location, elevation, and pressure needed for effective irrigation using the selected method of irrigation. Additionally, after water has been delivered and applied effectively, control of surface runoff and subsurface water tables must be considered. Principles for controling the delivery, measurement, and disposal of irrigation water are discussed in Part 686.

Figure CO680.1 Climatic Zones of Colorado

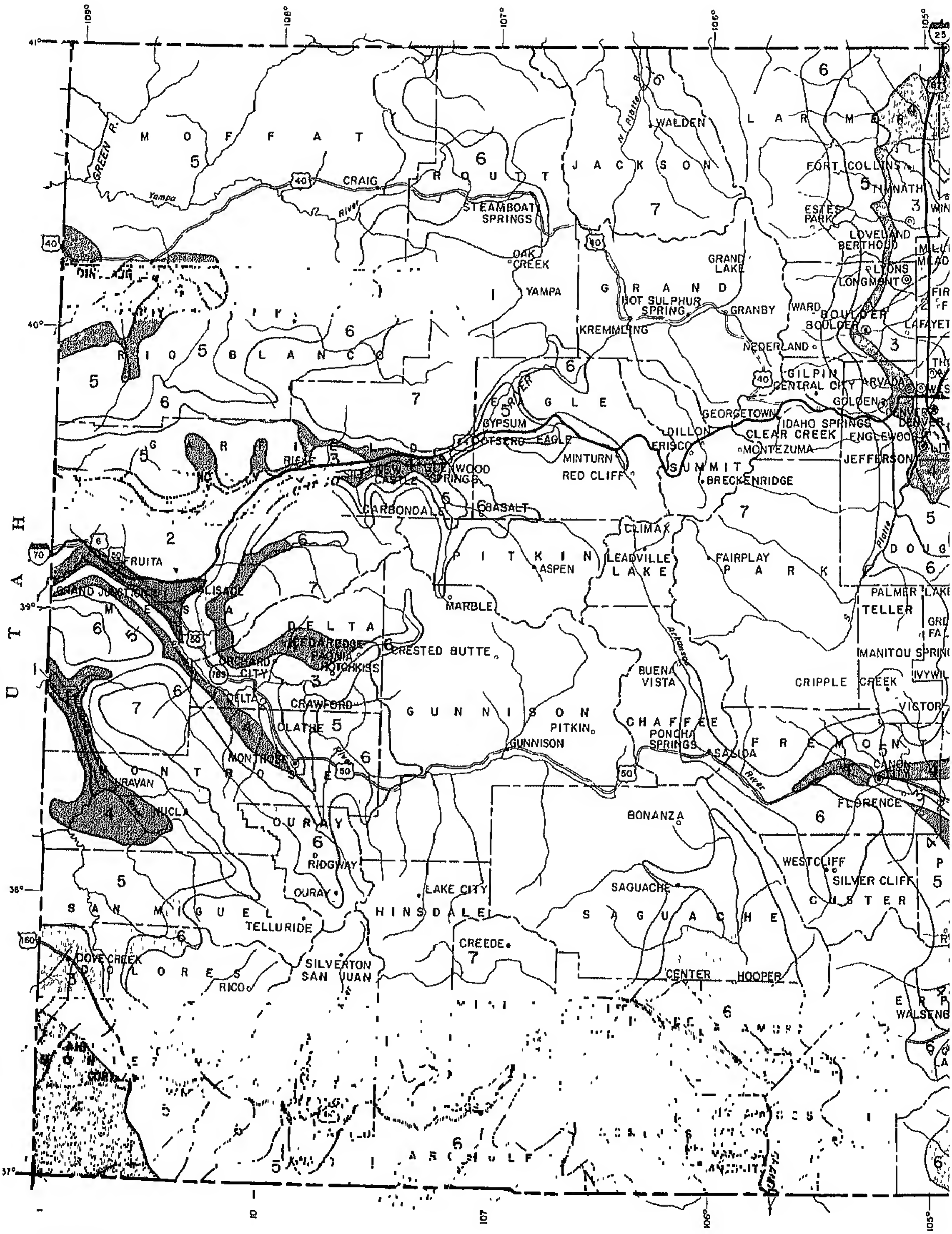

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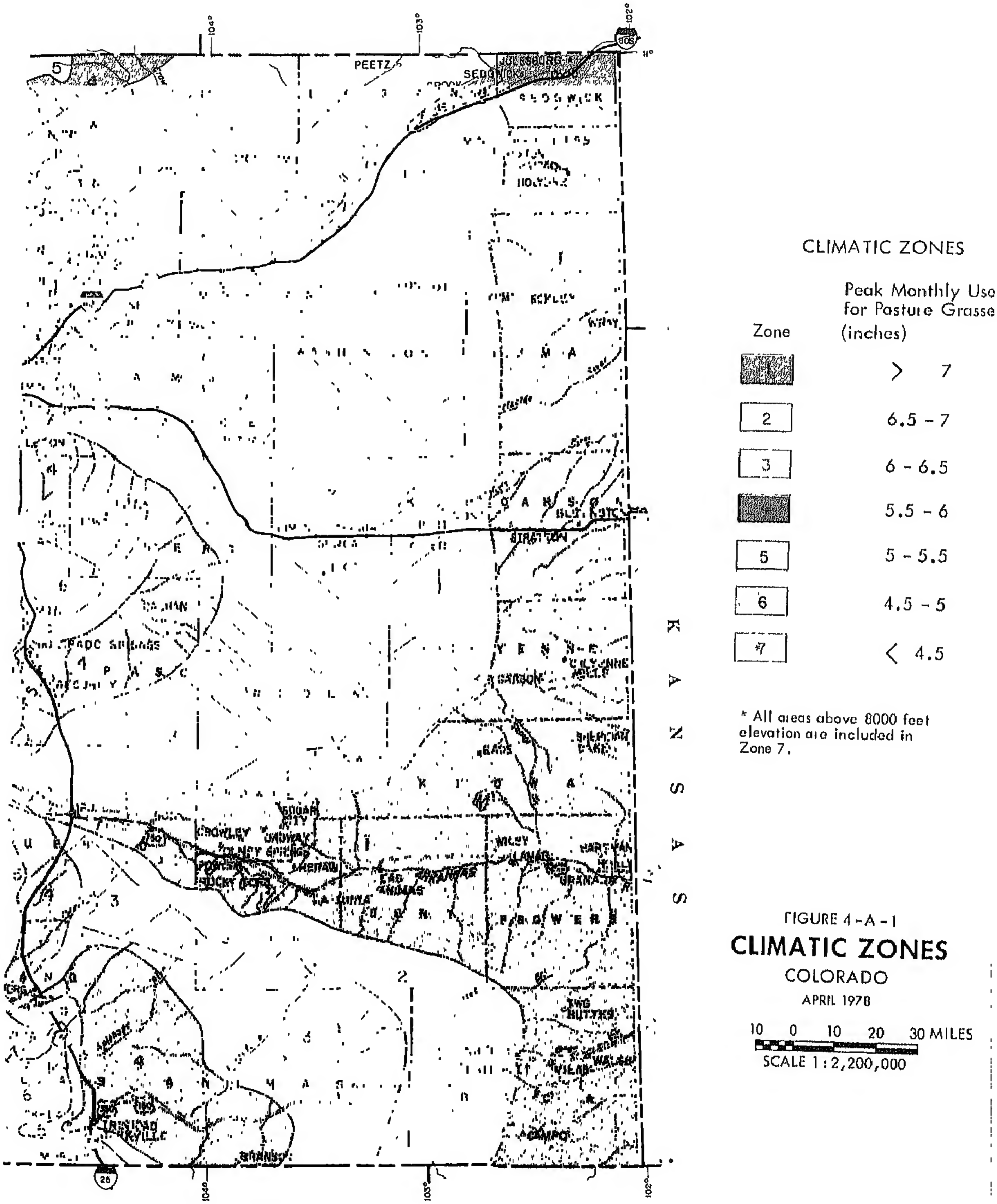
Figure C0680.1-2 Climatic Zones of Colorado



C0680.9

C0680.9 Irrigation water management.

(a) The concept of irrigation water management involves the following premises:

(1) The amount of water applied at each irrigation is determined by the available water holding capacity and the management allowed depletion (MAD) of the soil moisture.

(2) The water is applied at such a rate that wasteful runoff does not occur and soil does not erode.

(3) The timing of irrigations is such as to meet crop needs at critical growth stages.

(4) The application rates and timing result in a minimum of water loss.

(b) Irrigation water management should be practiced with each crop during each irrigation throughout each growing season. Scheduling techniques have been developed that allow the farmer to fully utilize automated methods of irrigation. Currently, evapotranspiration data is being provided to farmers on the eastern plains thru local radio stations and newspapers. Irrigation water management is discussed in Part 687 of the Guide.

C0680.10 Conservation irrigation systems planning.

(a) Part 688 of the Guide includes a format and procedure which can be used in planning irrigation systems and evaluating water management.

C0680.11 Economic evaluations

(a) Part 689 includes criteria to be used in making pumping cost studies and other economic factors that may be used in planning and design.

C0680.12 Use of water supply forecasts

Advanced estimates of available water supply based on snow survey data are now available to water users. Use of these estimates in planning the type and extent of crops to be planted is discussed in Part 690 of the Guide.

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Part 681 - Soils

Part 681 - Soils

SUBPART A - GENERAL

C0681.1 Soil series and phases.

(a) Soils with profiles that are almost alike make up a s series. Except for different texture in the surface layer, of the soils of one series have major horizons that are simil in thickness, arrangement, and other important characteristic Each soil series is named for a town or other geographic feat near the place that it was first observed and mapped. All so having the same series name are essentially alike in those characteristics that effect their behavior in the undisturbed landscape.

(b) Soils of one series can differ in surface texture and slope, stoniness, or some other characteristic that affects i use. On the basis of such differences, a soil series is divi into phases. The name of a soil phase indicates a feature th affects management. For example, Aphishipa clay loam is one several phases within the Apishipa series.

C0681.2 Irrigated soils identification.

(a) Most of the irrigated soils in the State are listed i the guide by both series and phase. Soil mapping symbols are shown, since symbols for the same soil may not be the same in published soil survey reports. Each field office and other us are encouraged to add map symbols for their particular locali to facilitate use of the guide with soil maps. Each field off should also add to or modify the soils listed in the guide as additional soils data are developed.

Part 681 - Soils

SUBPART B - SOIL IRRIGATION PARAMETERS

C0681.10 Intake families and sprinkler application rates.

(a) Each soil has its own intake characteristic, but the difference between some soils is so minor that many can be considered together. Water-intake rate also varies with the method of water application. Intake families or groups have been developed for most water application methods. A more detailed explanation of soil intake characteristics and intake families is contained in Chapter 1 of National Engineering Handbook, Section 15, Irrigation. Procedures for determining intake rate are discussed in Part 687.

(1) Cylinder-infiltrometer data are used for border and contour ditch methods of irrigation. Intake families shown in the guide for the soils listed are based on actual tests where available. Where test data are lacking, the intake family is estimated by comparison with similar soils, particularly the surface soil texture.

(2) Inflow-outflow measurement data are used for furrow and corrugation methods of irrigation. This type of data are lacking in Colorado. Values shown in the guide were obtained by comparing intake values for furrows with cylinder intake values.

(3) The maximum application rate for a soil under sprinkler irrigation can be determined by measuring the application rate at selected points in the distribution pattern of operating sprinklers. This type of data are also lacking. The values presented in this guide should be used where more specific data are not available.

C0681.11 Available water holding capacity.

(a) The amount of water stored in the soil for plant use is dependent upon its texture and depth. As water is added to a dry soil, it is distributed through the soil pores or void spaces where it is held by adhesive and cohesive forces. It displaces air in the pore spaces and eventually fills them. The water in the larger pores moves downward as free water and the pores are again filled with air. The amount of water retained by the soil particles is called the field capacity of the soil. For fine textured (silt and clays) soils the pore spaces are very small, therefore, there will be fewer pore spaces filled with air and the field capacity will be high.

)681.11(b)

(b) Energy must be expended by plants to remove water from ıe soil. The force (tension) with which the water is held əpends upon the amount of water in the soil--the smaller the nount, the greater the tension. When the moisture content ıcreases to a point that the plant cannot exert sufficient force ɔ extract moisture from the soil, the plant will wilt. This ıisture content is called the wilting point. Generally sandy ɔils drain almost completely at low tension, whereas fine-ıxtured clays and silts still hold a considerable amount of ɔisture at such high tension that plants growing in the soil ilt.

(c) The amount of water between the wilting point and field əpacity is the water available for plant use and is called the ʼailable water capacity. The tension required to hold water in salt-free soil is generally as follows:

(1) For loamy and clayey soils (i.e. sandy loams to clays): ıe difference between the values for one-third (1/3) and fifteen 5) bar tension.

(2) For sandy soils (i.e. sands to loamy sands): the ifference between the one-tenth (1/10) and fifteen (15) bar ənsion.

(d) Soil salts (salinity) decrease the amount of soil-water ıat is available for plant use. The available water holding əpacity for soils listed in the guide do not consider the ˀfects of salinity, but this must be considered in design and ənagement of irrigation systems.

(e) A more detailed explanation of available water holding əpacity is contained in Chapter 1 of National Engineering andbook, Section 15, Irrigation.

)681.12 Affect of salinity on available water.

(a) The available water content (AWC) values given on the :S-SOILS-5 forms and in the "Soil Properties and Design Values ɔr Irrigation" tables (C0681.20) are for salt free soil. Where lts accumulate in the root zone the amount of water the crop an extract from the soil is reduced.

(b) Figure C0681.1 shows the percent reduction in available ter that can be expected for various salinity concentrations.

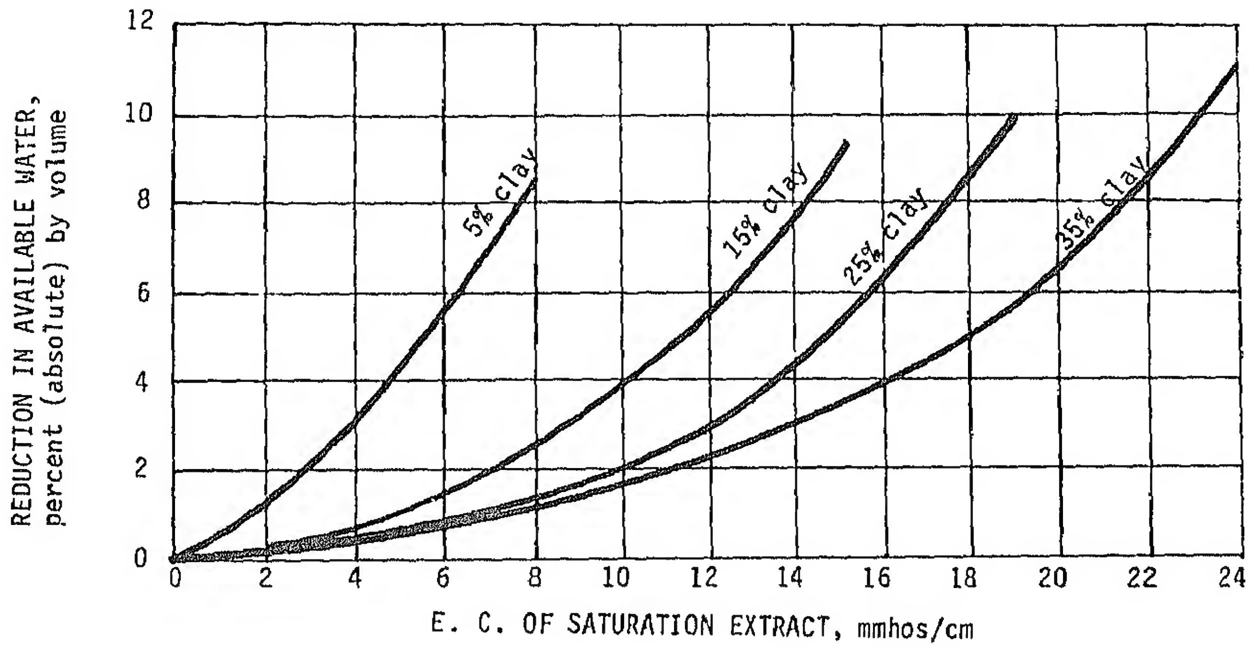

Figure C0681.1 Reduction in available water in salt affected soils.

C0681.13 Soil erosion rating factor (K).

(a) The capability of a soil to resist erosion is a function of the physical and chemical properties of the soils surface layer. The most significant soil characteristics affecting soil erodibility are texture, organic matter content, soil structure and permeability. The Universal Soil Loss Equation was developed to estimate sheet and rill erosion on cropland caused by the impact of falling rain drops. The Soil Erodibility Factor (K) in the equation is a rating of the soils susceptibility to particle detachment and transport by rainfall and runoff.

(b) Although the Universal Soil Loss Equation is not applicable to irrigated lands, soil erodibility factors do provide an indication of a soil's susceptibility to erosion by surface methods of irrigation and sprinkler application. These factors should be considered in selecting irrigation design slopes, along with other soil characteristics, when making crop management decisions.

C0681.14 Soil properties and irrigation design values.

(a) Section C0681.20 alphabetically lists most irrigated soils in Colorado and data relative to their characteristics for design and management of irrigation systems. Through the use of our computer it will be possible to list the soils found in each County or Field Office area. In this manner each Field Office will have a soils section tailored to its needs only.

C0681.15 Explanation of tables.

(a) Data contained in Section C0681.20 is as follows:

(1) <u>Heading</u> - The county and/or Field Office the information is applicable to.

(2) <u>Column (1) Survey Symbol</u> - This is the symbol that identifies the particular soil on the soils map.

(3) <u>Column (2) Depth and Texture</u> - Lists the name of the soil series and phase criteria and the range in depth, in inches, for soil horizons significant for irrigation followed by the soil texture(s) for the soil depth indicated.

(i) Symbols used are those prescribed for use on Form SCS-SOILS-5. National Soils Handbook - Part II, 407.1(a)(ii). The texture and modifiers used are as follows:

Modifier		Texture		Terms Used in Lieu of Texture	
BY	Bouldery	COS	Coarse sand	CEM	Cemented
CB	Cobbly	S	Sand	DE	Diatomaceous earth
CBA	Angular cobbly	FS	Fine sand		
CBV	Very cobbly	VFS	Very fine sand	G	Gravel
CN	Channery	LCOS	Loamy coarse sand	IND	Indurated
GR	Gravelly	LS	Loamy sand	MRAL	Marl
GRC	Coarse gravelly	LFS	Loamy fine sand	MUCK	Muck
GRF	Fine gravelly	LVFS	Loamy very fine sand	GYP	Gypsiferous
GRV	Very gravelly	COSL	Coarse sandy loam	MPT	Mucky - Peat
MK	Muck	SL	Sandy loam	PEAT	Peat
PT	Peaty	FSL	Fine sandy loam	SG	Sand and gravel
SH	Shaley	VFSL	Very fine sandy loam	SP	Sapric material
SR	Stratified	L	Loam	UWB	Unweathered bedrock
ST	Stony	SIL	Silt loam		
STV	Very stony	SI	Silt	VAR	Variable
		SCL	Sandy clay loam		
		CL	Clay loam		
		SICL	Silty clay loam		
		SC	Sandy clay		
		SIC	Silty clay		
		C	Clay		

C0681.15(a)(3)(ii)

(ii) Where more than one texture is used on a line, they are separated by commas (e.g. L, SIL, is loam and/or silt loam). If modifiers are used, they are attached to the texture by a hyphen (e.g., GR-SL is gravelly sandy loam). If a layer is stratified, SR is used as a modifier and the end members of the textural range are all connected by hyphens, (e.g., SR-S-L is stratified sand and loam and SR-GRV-S-GRV-SL is stratified very gravelly sand and very gravelly sandy loam).

(4) Column (3) EC. Lists the range in electrical conductivity in mmhos for the soil horizon when available.

(5) Column (4) AWC. Shows the available water capacity in inches per inch of depth for each soil horizon listed in column (2) for salt free soil.

(6) Columns (5) through (8). Lists the total available water capacity by root zone depth for 2, 3, 4 and 5 foot depths. When using these values for design, the contribution from groundwater needs to be considered for soils with a seasonal high water table. The effects of salinity and other parameters that affect availability of water are not considered. Appropriate adjustments need to be made in design and management of irrigation systems.

(7) Column (9) Depth to Water Table. Lists the seasonal water table depth as greater or less than 6 feet.

(8) Column (10) K Value (Erodibility Factor in USLE). Shows the approximate average K value for soils listed in column (2). (To be used in design of irrigation systems as a guide to minimize erosion by applied irrigation water).

(9) Column (11) T. Lists the allowable (T) soil erosion loss value for the soil.

(10) Column (12) Cylinder Intake Family. Lists the estimated cylinder intake family(s) for the soil listed in column (2).

(11) Column (13) Furrow Intake Family. Lists the estimated furrow intake family(s) for the listed soils. This is a design value. Initial and final soil intake will be greater and then less than this value.

(b) New lands that require initial conditioning, including water table control, leaching and special cropping to improve porosity, permeability and intake rate, may have intake rates significantly different from these shown.

Part 681 - Soils

SUBPART C - TABLES

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Part 682 - Crops

Part 682 - Crops

SUBPART A - GENERAL

C0682.1 Irrigation and crop production.

(a) The objective of irrigation is to supplement natural precipitation to meet the moisture requirements of the crop. When crop stress due to moisture shortage is prevented by proper and timely irrigation, other factors become inhibitors to production. These factors include poor soil structure and tilth, low fertility, poor stands, weeds, insects, and diseases. Much of the water applied through irrigation may be wasted unless sound farming practices are followed.

(b) Soil structure and tilth must be favorable for good aeration, initial water intake, and soil permeability. Soil tilth helps prevent runoff, water waste, and reduces water erosion. Tilth and structure can be maintained or improved by avoiding cultivation of wet fields; by the addition of manure, or by plowing under green manure crops; using grass and legumes in rotation; stubble mulch farming; and minimum tillage. On irrigated pastures, cattle should be excluded after irrigation until the surface soil is dry.

(c) Low fertility, or an imbalance of nutrients, is often the limiting factor in crop production. The well-fed plant uses water more efficiently than a plant that is starved or lacking in some nutrient elements. Total water use by a healthy, well-fed plant is greater than for a plant deprived of plant food, but the production per unit of water is much greater. Fertility problems can be corrected by the application of barnyard manure, commercial fertilizer, or an improved cropping system. Soil tests, observations, and field experience help determine the type and amount of fertilizers to use.

(d) Adequate soil moisture, fertility and good soil conditions will not ensure high production unless the irrigation farmer controls pests, uses high quality seed of adapted varieties, and uses timely operations. Weeds, insects, and diseases may be a greater problem on irrigated land than on dryland. Crop types and varieties should be selected to fit the soil and irrigation system. Plant population should be increased in most cases to take advantage of water added by irrigation.

C0682.2 Plant-water relationships.

(a) Plants remove water from the soil through evapotranspiration a process commonly called consumptive use. It includes water used by plants in transpiration and growth, and that which is evaporated from the adjacent soil surface and also from precipitation intercepted by plant foliage. In designing an irrigation system, the technician must know how water is used and in what quantities by the plants. He must also know how much water is held by the soil and the quantity that is available for plant use.

(b) Transpiration is the process by which water is removed from the soil by a plant, moved to the leaves and lost to the atmosphere in vapor form. In irrigation practice, the moisture retained by the plant is included. Transpiration occurs mostly during day-time hours.

C0682.3 Moisture extraction patterns.

(a) Moisture is removed by the plant roots from a depth equal to the effective root zone. Each species has its own characteristic rooting pattern; some have a tap root that penetrates deeply into the soil under favorable conditions; others develop shallow primary roots with many lateral roots. For most plants, water absorbing roots are greatest in the upper part of the root zone. Extraction is most rapid in the zone of greatest root concentration. Almost all plants growing in a uniform soil with an adequate supply of water have similar moisture extraction patterns.

(b) In uniform soils that are fully supplied with available water, the moisture extraction pattern is approximately as follows:

First 1/4 of Root Zone------------------------40 percent
Second 1/4 of Root Zone-----------------------30 percent
Third 1/4 of Root Zone------------------------20 percent
Fourth 1/4 of Root Zone-----------------------10 percent

(c) In nonuniform soils, the amount of moisture available for crop growth is usually determined by the soil layer that has the lowest amount of available water. If the top layer of a soil has a low water-holding capacity, the available moisture is soon exhausted. If the water supply is not immediately replenished, plants must draw from lower levels at a less efficient rate and their growth is retarded. Any level in the soil that has a low water holding capacity limits the total amount of moisture plants can use.

(d) The usual extraction pattern for a given crop is changed by any barrier in the soil that restricts root development. Similarly, if the moisture level in the upper layer(s) of the soil drops much below field capacity, a plant extraction pattern will differ from its usual pattern.

C0682.4 Critical growth periods.

(a) For maximum production and the most efficient use of water, plants must have ample moisture throughout the growth season. This is most important during critical periods of growth and development. Although plants indicate moisture stress by various symptoms, yields will usually be reduced by the time the plant shows stress. Time of irrigation can be determined by examination of the soil for moisture content. The feel and appearance of the soil at various moisture contents are given in Part 687 of this Guide. Symptoms of moisture stress, critical water requirement periods, and other irrigation considerations for major crops are shown in Table C0682.30

C0682.5 Water depletion levels.

(a) The most desirable moisture level has not been determined quantitatively for all crops. In the arid and semi-arid regions of the western states, where nearly all moisture for crop growth is supplied by irrigation, the desirable minimum soil-moisture level is about 50 percent. Some crops, however, require a higher moisture level for quality control and high yields. Soils with very low intake rates are usually irrigated when the moisture to be replaced can be absorbed in 12 (by ponding) to 48 (in furrows) hours.

Part 682 - Crops

SUBPART B - CROP ADAPTATION

C0682.10 Locally adapted crops.

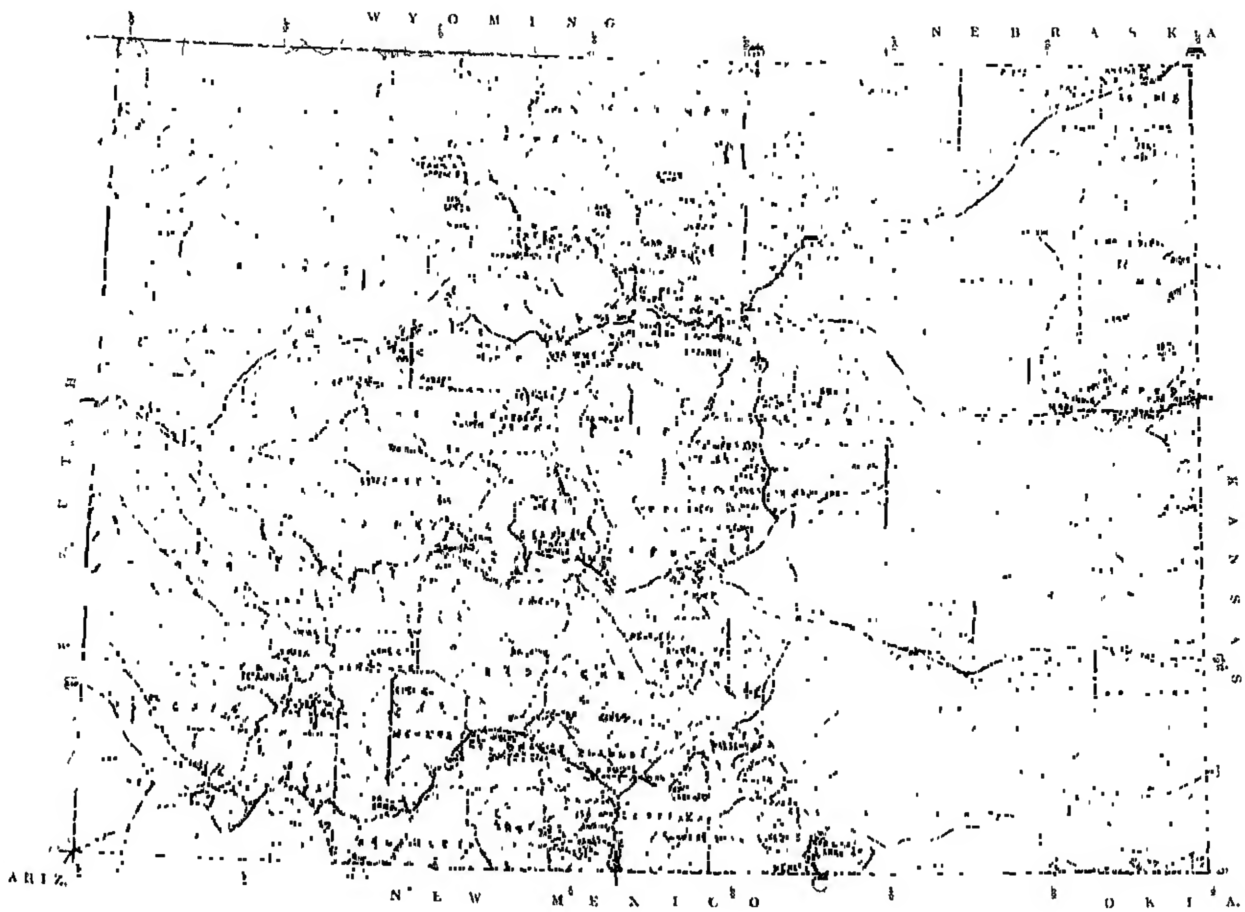
(a) The growing seasons in Colorado vary considerably, but are generally short. As an example, Grand Junction has approximately 210 days between killing frosts. Other areas of the State are Greeley 166, Lamar 186, Monte Vista 105, Cortez 153, and Craig 120 days.

(b) The Major Land Resource Areas (MLRA) in the State are shown in Figure C0682.1 The valley areas within each MLRA have similar climatic conditions that are significant to agriculture.

C0682.11 Crops and irrigation methods.

(a) The method of irrigation must be compatible with the crop being grown. Most crops, however, are adaptable to several methods of irrigation. Crops that require cultivation for weed control generally limit the irrigation method to furrow or sprinkler application.

Figure CO682.1 Major Land Resource Area (MLRA



LAND RESOURCES REGIONS AND MAJOR LAND RESOURCES AREAS

D WESTERN RANGE AND IRRIGATION REGION

- 34A Central Desertic Basins
- Central Desertic Mountains and Foothills
- Central Cold Desertic Plateaus
- Colorado and Green River Plateaus
- San Juan River Valley Mesas and Plateaus
- Arizona and New Mexico Mountains

ROCKY MOUNTAIN AND FOREST REGION

- Wasatch and Uinta Mountains
- 48A Southern Rocky Mountains
- Southern Rocky Mountain Parks
- Southern Rocky Mountain Foothills(Dry)
- Southern Rocky Mountain Foothills
- High Intermountain Valleys

G WESTERN GREAT PLAINS AND RANGE AND IRRIGATED REGION

- Central High Plains
- Upper Arkansas Valley Rolling Plains
- Upper Arkansas Valley Rolling Plains(Dry)
- 70 Pecos Canadian Plains and Valleys

CENTRAL GREAT PLAINS WINTER WHEAT AND RANGE REGION

- 72 Central High Tableland
- Southern High Plains

LAND RESOURCES REGIONS AND MAJOR LAND RESOURCE AREAS

COLORADO

APRIL 1983

10 0 10 20 30 40 50 60 MILES

Part 682 - Crops

SUBPART C - SALINITY TOLERANCE OF CROPS

C0682.20 Salt Tolerance of crops.

(a) Generally, all irrigation water contains soluble salts. These salts tend to accumulate in irrigated soils and are sometimes harmful to crop production. These conditions are particularly common where most of the moisture supply comes from irrigation. The problem will eventually become serious if irrigation is not sufficient to leach the accumulating salts or if the soil is poorly drained.

(b) The salinity found in various parts of the root zone does not remain constant. Due to water use by the crop and evaporation from the soil surface, the salts are left behind in a shrinking volume of soil water. If the salt content cannot be held or reduced to a point compatible with the crop, plant growth is retarded and the plant may die.

(c) Salt molecules, in solution, split up to produce electrically charged particles called ions. These ions conduct an electrical current. The greater the concentration of ions, the greater the conductivity of the solution. Thus, the salinity of a soil can be determined by measuring the electrical conductivity in millimhos per centimeter, the usual term in which soil salinity is reported. Table C0682.31 "Approximate Yield Decrease for Certain Crops due to Salinity", shows the effects of salinity on crop production.

Part 682 - Crops

SUBPART D - TABLES

C0682.30

Table C0682.30 Critical Growth Periods For Major Crops

Crop	Moisture Stress	Critical Period	Other Considerations
Alfalfa	Darkening color, then wilting	Early Spring and immediately after cuttings	Normally 3-4 inches of water is needed between cuttings. Fall irrigation is desirable.
Corn	Curling of leaves by mid-morning	Tasseling, silk stage until grain is fully formed	Needs adequate moisture from germination to dent stage for maximum production.
Sorghum	Curling of leaves by mid-morning	Boot, bloom and dough stages	Yields are reduced if water is short during seed development.
Sugar Beets	Leaves wilting during heat of the day.	Post thinning	Excessive fall irrigation lowers sugar content.
Beans	Wilting	Bloom and fruit set	Yields are reduced if water is short at bloom or fruit set.
Small Grain	Dull green color, then firing of lower leaves	Boot and Bloom stage	Last irrigation at milk stage.
Potatoes	Wilting during heat of the day	Tuber formation to harvest	Moisture stress during critical period may cause cracking of tubers.
Onions	Wilting	Bulb formation	Keep wet during bulb formation, let soil dry near harvest.
Tomatoes	Wilting	After fruit set	Wilt and leaf rolling can be caused by disease.
Cool Season Grass	Dull green color, then wilting	Early Spring, early fall	Critical period for seed production is boot to head formation.
Fruit Trees	Dulling of leaf color, and drooping of growing points	Any point during growing season	Stone fruits are sensitive to moisture stress during last two weeks prior to harvest.

Table C0682.31 Approximate Yield Decrease for Certain Crops Due to Salinity

Crop	0% ECe1/	10% ECe	25% ECe	50% ECe	MAXIMUM ECe2/
Field Crops					
Barley 3/	8.0	10	13	18	28
Beans	1.0	1.5	2.3	3.6	6.5
Corn	1.7	2.5	3.8	5.9	10
Cowpea	1.3	2.0	3.1	4.9	8.5
Safflower	5.3	6.2	7.6	9.9	14.5
Sorghum	4.0	5.1	7.2	11	18
Soybean	5.0	5.5	6.2	7.5	10
Sugarbeet4/	7.0	8.7	11	15	24
Wheat3/	6.0	7.4	9.5	13	20
Vegetable Crops					
Beans	1.0	1.5	2.3	3.6	6.5
Beets4/	4.0	5.1	6.8	9.6	15
Broccoli	2.8	3.9	5.5	8.2	13.5
Cabbage	1.8	2.8	4.4	7.0	12
Cantaloupe	2.2	3.6	6.7	9.1	16
Carrot	1.0	1.7	2.8	4.6	8
Cucumber	2.5	3.3	4.4	6.3	10
Lettuce	1.3	2.1	3.2	5.2	9
Onion	1.2	1.8	2.8	4.3	7.5
Pepper	1.5	2.2	3.3	5.1	8.5
Potato	1.7	2.5	3.8	5.9	10
Radish	1.2	2.0	3.1	5.0	9

Table C0682.31 Approximate Yield Decrease for Certain Crops Due to Salinity

Vegetable Crops (continued)					
Tomato	2.5	3.5	5.0	7.6	12.5
Spinach	2.0	3.3	5.3	8.6	15
Sweet Corn	1.7	2.5	3.8	5.9	10
Sweet Potato	1.5	2.4	3.8	6.0	10.5

Forage Crops

Crop	0% ECe1/	10% ECe	25% ECe	50% ECe	MAXIMUM ECe2/
Alfalfa	2.0	3.4	5.4	8.8	15.5
Barley (hay)	6.0	7.4	9.5	13.0	20
Bermuda grass	6.9	8.5	10.8	14.7	22.5
Clover, alsike, ladino, red, strawberry	1.5	2.3	3.6	5.7	10
Crested Wheat grass	3.5	6.0	9.8	16	28.5
Harding grass	4.6	5.9	7.9	11.1	18
Lovegrass	2.0	3.2	5.0	8.0	14
Meadow foxtail	1.5	2.5	4.1	6.7	12
Orchard grass	1.5	3.1	5.5	9.6	17.5
Perennial rye grass	5.6	6.9	8.9	12.2	19
Sudan grass	2.8	5.1	8.6	14.4	26
Tall fescue	3.9	5.8	8.6	13.3	23
Tall wheat grass	7.5	9.9	13.3	19.4	31.5
Trefoil, big	2.3	2.8	3.6	4.9	7.5
Vetch	3.0	3.9	5.3	7.6	12
Wheatgrass (fairway)	7.5	9.0	11	15	22
Wildrye beardless	2.7	4.4	6.9	11.0	19.5

C0682.31

Table C0682.31 Approximate Yield Decrease for Certain Crops Due to Salinity

Crop	0% ECe1/	10% ECe	25% ECe	50% ECe	MAXIMUM ECe2/
	Fruit Crops				
Apple	1.7	2.3	3.3	4.8	8
Apricot	1.6	2.0	2.6	3.7	6
Blackberry	1.5	2.0	2.6	3.8	6
Boysenberry	1.5	2.0	2.6	3.8	6
Grape	1.5	2.5	4.1	6.7	12
Peach	1.7	2.2	2.9	4.1	6.5
Plum	1.5	2.1	2.9	4.3	7
Raspberry	1.0	1.4	2.1	3.2	5.5
Strawberry	1.0	1.3	1.8	2.5	4
Walnut	1.7	2.3	3.3	4.8	8

1/ ECe means electrical conductivity of the saturation extract of the soil reported in millimhos per centimeter at 25°C.

2/ Maximum ECe means the maximum electrical conductivity of the soil saturation extract that can develop due to the listed crop withdrawing soil water to meet its evapotranspiration demand. At this salinity, crop growth ceases (100% yield decrement) due to the osmotic effect and reduction in crop water availability to zero.

3/ Barley and wheat are less tolerant during germination and seedling stage. ECe should not exceed 4 or 5 mmhos/cm.

4/ Sensitive during germination. ECe should not exceed 3 mmhos/cm for garden beets and sugar beets.

Source: Data as reported by Maas and Hoffman (in press); Bernstein (1964), and University of California Committee of Consultants (1974).

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Part 683 - Water Requirements

Part 683 - Water Requirements

SUBPART A - GENERAL

C0683.1 Net irrigation water requirement.

(a) The net irrigation water requirement is defined as the water supplied by irrigation to satisfy evapotranspiration, leaching and miscellaneous water requirements that are not provided by water stored in the soil and precipitation that enters the soil. Precipitation that drains through a soil is not effective unless it reduces the leaching requirement. The irrigation requirement is defined as:

$$W_r = W_{et} + W_1 + W_m - R_e - W_s,$$

Where

W_r = irrigation water requirement for the period considered.

W_{et} = evapotranspiration; the quantity of water required for transpiration or building of plant tissue and evaporation from the soil and interception of precipitation during a specific period of time.

W_1 = leaching requirement; the quantity of water required to remove soluble salts from the root zone by the downward passage of water.

W_m = miscellaneous water requirements; the quantity of water used to aid in germination and emergence of small seeds, to prevent frost damage to crops and for plant cooling.

R_e = effective rainfall.

W_s = the decrease in soil water that can be utilized during the period.

C0683.2 Consumptive use and methodology.

(a) General Methodology.

(1) Consumptive use of water or evapotranspiration is one of the important elements of the hydrological cycle from the time water falls upon the land as precipitation until it reaches the ocean or is returned to the atmosphere.

C0683.2(a)(2)

(2) Consumptive use data is essential for estimating water requirements for irrigation as well as for estimating municipal and industrial water needs. From research studies, formulas have been developed relating consumptive use and climatological data. The net irrigation water requirement can be estimated by transposing observed consumptive use data from one area to another where few or no data, except climatological records, are available by these formulas. Direct transfer of consumptive use data to an area with widely different climatic conditions is not valid.

(b) Method of Computation.

(1) In areas for which few or no measurements of consumptive use are available, it is necessary to estimate consumptive use from climatological data. The Soil Conservation Service uses the Blaney-Criddle method, with some modifications, for this purpose. The Blaney-Criddle procedure gives sufficiently accurate results when used for the purpose it was originally developed--that is, for estimating <u>seasonal</u> consumptive use.

(2) The basic assumption is that consumptive use (Et) varies directly with the sum of the products of mean monthly air temperature and monthly percentage of daytime hours for an actively-growing crop with adequate soil moisture. Therefore:

$$Et = KF = \Sigma kf,$$

Where

Et = estimated evapotranspiration (consumptive use),

K = empirical consumptive use co-efficient (season or growing period),

F = sum of monthly consumptive use factors, f,

f = tp/100 (where "t" is mean monthly air temperature and "p" is mean monthly percentage of annual daytime hours),

k = monthly consumptive use coefficient.

(3) The seasonal crop coefficients are not constant for consecutive short periods throughout the growing season. Therefore, the Soil Conservation Service has made two modifications to the original procedure to obtain reasonably accurate estimates of short-period consumptive use.

(4) One modification requires using climatic coefficients that are directly related to the mean air temperature for each of the consecutive short periods which constitute the growing season. The other requires the use of coefficients which reflect the influence of crop growth stages on consumptive use rates. Therefore:

$$k = (kt)(kc)$$

Where

k = climatic coefficient related to mean air temperature,

kt = 0.0173t - 0.314

kc = coefficient reflecting the growth stage of the crop.

(5) The procedure for determining irrigation water requirements by this method is outlined in "Irrigation Water Requirements, SCS Technical Release No. 21, revised 1970". Another important reference is "Crop Water Requirements" FAO Irrigation and Drainage Paper 24 revised 1977.

SUBPART B - CONSUMPTIVE USE REQUIREMENTS

C0683.10 Irrigation climatic zones.

(a) The state is divided into seven zones with similar climatic conditions. These areas generally have similar peak period consumptive use rates for alfalfa and grass pasture. Table C0683.52 lists the applicable irrigated crops in each zone and gives the recommended design peak consumptive use rate in inches per day for various net depths of application. An 80% chance of effective rainfall was used as part of the input.

C0683.11 Monthly consumptive use rates.

(a) Water use by crops is influenced by several climatic factors, the most significant of which are temperature and sunlight. Since these values vary from day to day, water use rates will vary also. Consumptive use rates may be computed for any time period, however, monthly values are usually determined because of the availability of climatic data summarized on a monthly basis. Site specific daily data should be used when it is available.

(1) Table C0683.50 shows the estimated total consumptive use of water by season and month for various crops, the amount of effective rain-fall, net irrigation requirement for each crop, and growing seasons by crops for 27 weather stations disbursed throughout the seven climatic zones of the State.

(b) To determine the amount of irrigation water that should be applied each month, it is necessary to consider the following:

(1) The amount of water necessary to fill the root zone to field capacity.

(2) The amount to be added to each month's needs because of losses attributed to application efficiency. This will vary with soils, the irrigation system, field efficiencies, and the management provided by the operator.

(3) The amount to be applied near the end of the use season to restore the soil moisture level to field capacity. Some farmers prefer to add the leaching requirement at this time also.

C0683.12 Average daily and peak period consumptive use rates.

(a) While other factors may have a minor influence on the rate of consumptive use for a given period of time, air temperature and net depth of irrigation application have the greatest influence.

(1) Temperature. An analysis of daily mean air temperature records for any month at any location will show that the mean temperature for the warmest consecutive 5-day period will be greater than that for the warmest 10-day period. Likewise, the mean temperature for the warmest consecutive 10-day period will be greater than that for the warmest 15-day period, and so on. All will be greater than the mean monthly temperature. It is obvious that the shorter the period is in days, the greater will be the mean temperature, and therefore, the greater will be the consumptive use rate.

(2) Net Irrigation Application. The length of the period is that number of days in which the normal net irrigation application will last. Thus, smaller net irrigation applications will last for smaller periods of time and will result in a greater daily use rate for given time period and conversely higher net irrigation applications will result in a lower use rate.

(3) Daily Use Rates. Table C0683.51 shows average daily consumptive use rates as related to monthly use and net irrigation application. When the computed monthly consumptive use rate is for the peak use month, the tabular value is the peak period daily use rate.

(4) Peak Period Consumptive Use Rate. Information on peak period rates of consumptive use is needed to properly design irrigation systems. It is used to determine the minimum capacity requirements of main and lateral canals, pipelines, and other water conveyance or control structures. The peak period rates of water used by crops also influence the administration of streams and reservoirs from which irrigation water supplies are obtained.

(b) In irrigation system design, the peak period of consumptive use is the period during which the weighted average daily rate of consumptive use of the various crops grown in the project area is at a maximum. Different crops may have their peak rates of use at different times. Therefore, some crops may not be using water at their maximum rate during the project peak period.

(c) Table C0683.52 lists the common irrigated crops in each of the seven climatic zones, and gives the recommended design peak consumptive use rates in inches per day for various net depths of application.

(d) The irrigation frequency during peak period use may be calculated by the formula:1/

$$\text{Irrigation Frequency in Days} = \frac{\text{Net Irrigation Application}}{\text{Peak Period Daily Use Rate}}$$

<u>Example:</u>

Crop: Corn (4 foot root depth) in climatic zone 2

Soils: Billings clay loam 1-4% slope.

Available water: 50 percent of 7.92" = 3.96" or 4".

Net irrigation application: 4".

Daily peak period use with 4.0" net application is 0.25 inches (Table C0683.52)

$$\text{Irrigation frequency: } \frac{4.0}{0.25} = 16 \text{ days}$$

(e) Once the frequency of irrigation is determined, it is possible to design for ditch or pipeline capacities using the same information.

<u>Example</u>:

Crop: Corn - 120 acres
Irrigation efficiency: 60 percent
Gross application: 4" net application @ 60 percent efficiency: $\frac{4.0}{0.6}$ = 6.7" gross application
120 acres x 6.7" = 800 acre-inches every 16 days
800/16 = 50 acre-inches per day
50/24 = 2.08 acre-inches per hour

1/ For the irrigation frequency for periods other than the peak use period, determine the average daily use rate from Table C0683.51 and substitute this value for the peak period daily use rate in the formula.

C0683.12(e)

One cfs for one hour is equivalent to 0.992 acre-inches per hour. For ease in computation the conversion is taken to be: 1 cubic foot per second (cfs) is the same as one acre-inch per hour.

Conveyance design Q = 2.08 ac-in/hr or 2.1 cfs.

The following formula can also be used:

$$Q = \frac{\text{Peak daily Con. Use} \times 100 \times \text{acre}}{\text{Field Efficiency} \times 24} = \text{cfs needed}$$

Solution:

$$Q = \frac{0.25 \times 100 \times 120}{60 \times 24} = 2.1 \text{ cfs}$$

(f) The above example assumes a continuous water supply and provides the minimum conveyance design capacity. When the water delivery time is less than the irrigation frequency, the water delivery time is used instead of the irrigation frequency when using the gross application method. When using the Peak Consumptive Use formula, the result must be multiplied by the ratio of:

$$\frac{\text{Irrigation frequency (days)}}{\text{Water delivery time (days)}}$$

Example:

In the preceding example, assume a water delivery time of 66 hours or 2.75 days.

Gross Application Method

120 acres x 6.7" = 800 acre-inches in 66 hours
800/66 = 12.1 acre-inches per hour
Design Q = 12.1 cfs (use 12 cfs)

Peak Consumptive Use Formula

$$Q = \frac{0.25 \times 100 \times 120}{60 \times 24} \times \frac{16}{2.75} = 2.1 \times \frac{16}{2.75} = 12 \text{ cfs}$$

Part 683 - Water Requirements

SUBPART C - LEACHING REQUIREMENT

C0683.20 The leaching fraction.

(a) Salts are added to the soil as irrigation water is applied. If no water leaches below the root zone, salts will accumulate and eventually reduce yields. The amount of water required to control salt and maintain root-zone soil salinity low enough to produce an acceptable yield of a specific crop is the <u>leaching requirement</u>. It is dependent upon the salt load of the applied water and the salt tolerance of the crop. Satisfying the leaching requirement is easier on light textured soils than on heavy textured soils.

C0683.21 Determining the leaching fraction.

(a) There are several methods of calculating the leaching requirement for a specific crop and a given water supply. The following method is recommended:1/

$$LR = \frac{ECw}{5ECe-ECw} \quad \text{where,}$$

LR = Leaching requirement

ECw = Salinity of applied water

ECe = Soil Salinity tolerated by the crop

(b) Table C0682.31 gives soil salinity (ECe) values for selected crops and related yield reductions. Generally, yield reductions exceeding ten percent are not recommended.

(c) An irrigation water analysis and analysis of soil samples from each 1/4 of the root zone are needed to determine the leaching requirement. The arithmetic average of the soil ECe values for each 1/4 of the root zone should be used. The following example illustrates the calculation of leaching requirement.

(1) Given:

Crop - Alfalfa
ECw - 2.0
ECe - 3.4 (Table C0682.31; ten percent yield reduction)

1/ Rhoades, U.S. Salinity Laboratory, Riverside, California, 1977.

C0683.21(c)(2)

(2) $LR = \frac{ECw}{5ECe-ECw} = \frac{2.0}{(5(3.4) - 2.0)} = \frac{2.0}{15.0} = 0.13$ or 13%

(3) This means that 13 percent of the applied water must percolate below the root zone. The seasonal consumptive use requirement of the crop must be increased by this amount. Rainfall that enters the soil during or after the growing season is equally effective in satisfying a leaching requirement and is part of the leaching fraction.

(d) The amount of water to be applied to meet crop needs and leaching requirement is computed as follows:

$$A_w = \frac{ET}{1 - LR} - (\text{Stored water + effective rainfall})$$

where:

A_w = Applied water requirement (net)
ET = Crop water requirement
LR = Leaching requirement
Stored water = Water in soil at start of growth
Effective rainfall = Rainfall entering the soil after start of growth

(1) The following example illustrates computation of applied water requirement:

(i) Given:

ET = 30 inches
LR = 13 percent
Stored water = 6 inches
Effective rainfall = 4 inches

(ii) $Aw = \frac{ET}{1 - LR} - (\text{stored water + effective rainfall})$

$$A_w = \frac{30}{1 - .13} - (6 + 4) = 34.5 - 10 = 24.5 \text{ inches}$$

Part 683 - Water Requirements

SUBPART D - OTHER WATER REQUIREMENTS

C0683.30 Cooling.

(a) Water, applied through a sprinkler system is an effective way to reduce the air temperature for crops adversely affected by high temperatures. The entire field must be covered with a fine mist either continuously or by frequent cycling of the application system. This practice can reduce field temperatures as much as 15 degrees (F) during periods of high temperature.

C0683.31 Frost protection.

(a) Application of water, by a sprinkler system is an effective way to protect crops from freezing. It also is effective in preventing early blossoming in orchards.

(b) For frost protection, the entire field must be covered with a fine mist of water during freezing temperatures. The system must be turned on before air temperature at plant level reaches 32 degrees F. The plants become covered with ice; however, the freezing of water releases latent heat that is absorbed by the plants, and this gives protection until the temperature drops too low. Protection is usually obtained for temperatures somewhat below 25 degrees F. Damage will occur if the water is turned off before the temperature has risen and the ice has melted from the plants. Frost protection is more readily adapted to low-growing vegetable crops.

(c) To prevent premature blossom set in orchards, a fine mist is sprayed over the trees whenever the temperature rises above approximately 45 degrees F. The cooling effect of the water and evaporation will cause the trees to remain dormant until the danger of damaging freeze periods is past.

Part 683 - Water Requirements

SUBPART E - IRRIGATION WATER QUALITY

C0683.40 Irrigation water characteristics.

(a) Most of Colorado depends on precipitation in the mountains, much of which falls as snow, for its water supply. The passage of water over and through the ground permits the solution of many soluble products of rock weathering, and when the water rises again to the surface it contains dissolved materials.

(b) Low humidity, high temperatures, and winds contribute to the concentration of saline material in streams, lakes, and in the upper layers of the soil. These factors also favor the concentration of salts in ground water. Both natural runoff and irrigation contribute to the problem, either by salt concentration or salt loading. As water is consumed through evaporation and transpiration, its mineral constituents remain, thereby, increasing its concentration in the ground water. Salt loading occurs as ground water dissolves subsurface minerals and carries them off while flowing back to the surface at a stream channel.

(c) Suspended silts and sediments are deposited on the irrigated fields by irrigation water. These particles tend to seal the soil surface, lower its infiltration rate and thereby increase the amount of runoff.

(d) The amount of salt contained in the water also varies with the time of year. In the spring, during high run-off, most streams reach a low in concentration of dissolved solids. Later in the year, when the stream reaches a low volume, the quality is poorest. It must be kept in mind that a given irrigation water is not always of the same quality during the entire irrigation season.

C0683.41 Water quality requirements.

(a) The most serious long lasting variable in the quality of irrigation water is the amount and type of salts that are dissolved in the water. High concentration of soluble salts directly interfere with crop growth, especially during germination and emergence stages and, if high in sodium, produce unfavorable physical conditions that further reduce plant growth and make soil and water management more difficult. Other characteristics that appear to be important are: total concentration of soluble salts, proportion of sodium to other cations, concentration of toxic elements, and under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium. The primary salts found in the water of the Arkansas, South Platte and Colorado rivers are those of calcium, magnesium and sodium. In most areas, there are enough calcium salts to keep the sodium, salts in check.

(b) Some dissolved constituents in irrigation water and their effects are as follows:

(1) Chlorides - The accumulation of chloride ions in plant tissues manifesting toxic symptoms is not an infallible indication of the specific toxicity of chloride. Many plants are no more sensitive to chloride salts than they are to concentrations of sulfate salts. Chloride burn occurs on citrus, peaches, avocados and grapevines. This chloride accumulation in the leaves is more pronounced in the presence of excess calcium ions than when sodium occurs in excess.

(2) Bicarbonate - In waters containing high concentrations of bicarbonate, there is a tendency for calcium and magnesium to precipitate as carbonates as the soil solution becomes more concentrated. As this precipitation occurs, the concentrations of calcium and magnesium are reduced, and the relative proportion of sodium is increased.

(3) Sediment - Sediment in irrigation water can have varied effects, depending upon the type of sediment. Coarse sediments deposit in conveyance systems and at the heads of fields and are costly to remove. Coarse sediments in water applied by sprinkler systems damage pumps and sprinkler nozzles and reduce their useful life. Damage may also occur to crops upon impact with the leaves or fruit.

(i) Suspended sediments are usually filtered out as the water enters the soil and may alter the intake rate. Suspended sediments in water applied by sprinkler systems may coat the leaves of crops and affect their growth.

(ii) Coarse sediments can usually be removed with sand traps, sluice boxes and settling ponds. These methods are not effective with suspended sediments. Irrigation methods may need to be limited to surface application with frequent cultivation to prevent surface sealing.

(c) The problems that result from using a poor quality water will vary both as to kind and degree but the most common problems are salinity and permeability.

(1) <u>Salinity</u> - A salinity problem related to water quality occurs if the total quantity of salts in the irrigation water is high enough that salts accumulate in the crop root zone. If excessive quantities of soluble salts accumulate in the root zone, the crop has difficulty extracting water from the salty soil solution. The approximate effects of salinity on yields of certain crops is shown in Part 682 - Crops, Table C0682.31.

(2) <u>Permeability</u> - A permeability problem related to water quality occurs when the rate of water infiltration into and through the soil is reduced by the affect of specific salts or lack of salts in the irrigation water. The crop may not be adequately supplied with water. Cropping difficulties caused by crusting of seedbeds, waterlogging of the surface soil, disease, weed, oxygen and nutritional problems may also occur. Permeability problems can be caused by low salinity content of the water and by high sodium concentrations.

(i) Low salinity waters tend to deplete soils of readily soluble minerals and salts. They have a tendency to rapidly dissolve all sources of calcium from the surface soil causing the finer soil particles to disperse, to fill pore spaces and to seal the soil surface. Very low salinity waters (electrical conductivity of the water, ECw, less than 0.2 mmhos/cm) often result in soil permeability problems. The lower the ECw, the greater is the potential for a permeability problem to occur.

(ii) High sodium in the irrigation water can cause severe soil permeability problems by causing soil dispersion. The affects of sodium is related to the relative amounts of sodium to calcium and magnesium in the soil. Permeability problems are also related to the carbonate and bicarbonate content of the irrigation water and need to be considered.

(iii) The adjusted Sodium Adsorption Ratio (adj. SAR) equation can be used to evaluate the potential hazard of sodium in addition to the effects of carbonate (CO_3) and bicarbonate (HCO_3).

C0683.41(c)(2)(iv)

$$\text{adj. SAR} = \frac{Na}{\sqrt{\dfrac{Ca + Mg}{2}}} \left[1 + (8.4 - pHc) \right]$$

where adj. SAR = Adjusted Sodium Adsorption Ratio
Na = Sodium concentration in meq/liter
Ca = Calcium concentration in meq/liter
Mg = Magnesium concentration in meq/liter
pHc = theoretical calculation of the pH in the water in contact with lime and in equilibrium with soil CO_2

Note: Values of pHc above 8.4 indicate a tendency to dissolve lime from the soil through which the water moves; values below 8.4 indicate a tendency to precipitate lime from the water applied.

(iv) Values used in the adj. SAR equation are expressed in milliequivalents per liter (meq/l). These values are obtained by dividing the concentration in milligrams per liter (mg/l) by the equivalent weight of the ionic compounds.

$$\text{meq/l} = \frac{\text{mg/l}}{\text{Eq. wt.}}$$

(v) Equivalent weights for the ionic compounds in the equation are as follows:

Compound	Symbol	Equivalent Weight	Compound	Symbol	Equivalent Weight
Calcium	Ca	20	Carbonate	CO_3	30
Magnesium	Mg	12.2	Bicarbonate	HCO_3	61
Sodium	Na	23			

C0683.41(c)(2)(vi)

(vi) The value of pHc can be determined using the following formula and table.

$$pHc = (pK_2 - pK_c) + p(Ca + Mg) + p(Alk)$$

*$(pK_2 - pK_c)$ is obtained from using the sum of Ca + Mg + Na in meq/l
*p(Ca + Mg) is obtained from using the sum of Ca + Mg in meq/l
*p(Alk) is obtained from using the sum of CO_3 + HCO_3 in meq/l

Sum of Concentration - meq/l	$pK_2 - pk_c$	p(Ca + Mg)	P(Alk)
.05	2.0	4.6	4.3
.10	2.0	4.3	4.0
.15	2.0	4.1	3.8
.20	2.0	4.0	3.7
.25	2.0	3.9	3.6
.30	2.0	3.8	3.5
.40	2.0	3.7	3.4
.50	2.1	3.6	3.3
.75	2.1	3.4	3.1
1.00	2.1	3.3	3.0
1.25	2.1	3.2	3.9
1.5	2.1	3.1	2.8
2.0	2.2	3.0	2.7
2.5	2.2	2.9	2.6
3.0	2.2	2.8	2.5
4.0	2.2	2.7	2.4
5.0	2.2	2.6	2.3
6.0	2.2	2.5	2.2
8.0	2.3	2.4	2.1
10.0	2.3	2.3	2.0
12.5	2.3	2.2	1.9
15.0	2.3	2.1	1.8
20.0	2.4	2.0	1.7
30.0	2.4	1.8	1.5
50.0	2.5	1.6	1.3
80.0	2.5	1.4	1.1

Table C0683.41 - Relationships of Sum of Concentration to other values.

* Obtained from water analysis.

C0683.41(c)(2)(vi)

To illustrate the above relationships, take an example water supply with ionic concentrations of Ca = 46 mg/l, Mg = 18 mg/l, Na = 178 mg/l, CO_3 = 13 mg/l, and HCO_3 = 223 mg/l.

In milliequivalents per liter:

Ca = 46/20 = 2.30 meq/l
Mg = 18/12.2 = 1.48 meq/l
Na = 178/23 = 7.74 meq/l
CO_3 = 13/30 = 0.43 meq/l
HCO_3 = 223/61 = 3.66 meq/l

Given:		
Ca = 2.30 meq/l	Ca = 2.30 meq/l	CO_3 = 0.43 meq/l
Mg = 1.48 meq/l	Mg = 1.48 meq/l	HCO_3 = 3.66 meq/l
Na = 7.74 meq/l		
Sum = 11.52 meq/l	Sum = 3.78 meq/l	Sum = 4.09 meq/l

From Table C0683.41 and using the equation for pHc:

$$pK_2 - pK_c = 2.3$$

$$p(Ca + Mg) = 2.7$$

$$p(Alk) = 2.4$$

$$pHc = 7.4$$

Substituting:

$$\text{adj SAR} = \frac{7.74\ (1 + [8.4 - 7.4])}{(3.78/2)^{0.5}}$$

$$= \frac{7.74(2)}{1.37}$$

$$= 11.3$$

C0683.42 Classification of Irrigation waters.

(a) Figure C0683.49 provides guidelines for determining the quality of irrigation water from the affects of salinity, permeability and toxicity. Laboratory data must be adequately related to field conditions or confirmed and tested by field trials or experience.

C0683.42(a)

Figure C0683.49 Guidelines for Interpretation of Water Quality for Irrigation

IRRIGATION PROBLEM	DEGREE OF PROBLEM		
	No Problem	Increasing Problem	Severe Problem
SALINITY (affects crop water availability)			
ECw (mmhos/cm)	< 0.75	0.75-3.0	> 3.0
PERMEABILITY (affects infiltration rate into soil)			
ECw (mmhos/cm)	> 0.5	0.5-0.2	< 0.2
adj. SAR 1/ 2/			
Montmorillonite (2:1 crystal lattice)	< 6	6-9 3/	> 9
Illite-Vermiculite (2:1 crystal lattice)	< 8	8-16 3/	> 16
Kaolinite-sesquioxides (1:1 crystal lattice)	< 16	16-24 3/	> 24
SPECIFIC ION TOXICITY (affects sensitive crops)			
Sodium 4/ 5/ (adj. SAR)	< 3	3-9	> 9
Chloride 4/ 5/ (meq/l)	< 4	4-10	> 10
Boron (mg/l)	< 0.75	0.75-2.0	> 2.0
MISCELLANEOUS EFFECTS (affects susceptible crops)			
NO_3-N (or) NH_4-N (mg/l)	< 5	5-30	> 30
HCO_3 (meq/l) [overhead sprinkling]	< 1.5	1.5-8.5	> 8.5
pH	[Normal Range 6.5 - 8.4]		

1/ Adj. SAR means adjusted Sodium Absorption Ratio and can be calculated using the procedure given in C0683.41(c).

2/ Values presented are for the dominant type of clay mineral in the soil since structural stability varies between the various clay types (Rallings, 1966, Rhoades, 1975). Problems are less likely to develop if water salinity is high; more likely to develop if water salinity is low.

3/ Use the lower range if ECw < .4 mmhos/cm;
Use the intermediate if ECw = 0.4 - 1.6 mmhos/cm;
Use upper limit if ECw > 1.6 mmhos/cm

4/ Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use the salinity tolerance table, C0682.31).

5/ With sprinkler irrigation on sensitive crops, sodium or chloride in excess of 3 meq/l under certain conditions has resulted in excessive leaf absorption and crop damage.

(Source: Water Quality for Agriculture - R.S. Ayers and D.W. Wescott, Food and Agriculture Organization (FAO-29) Rome, 1976.

PART 683 - WATER REQUIREMENTS

SUBPART F - TABLES

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(a)
Burlington, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	3/18 - 10/17	213	0	0	0.41	2.37	4.50	6.98	8.46	7.16	4.49	1.27	0	0	35.64
Pasture Grasses	3/18 - 11/5	232	0	0	0.35	2.05	3.73	5.68	7.02	6.13	3.95	2.04	0.11	0	31.06
Annuals															
Beans, Dry	5/28 - 9/5	100	0	0	0	0	0.20	4.40	8.16	5.99	0.47	0	0	0	19.22
Corn, Grain	5/1 - 10/5	157	0	0	0	0	2.00	4.41	7.76	7.16	4.31	0.36	0	0	26.00
Corn, Silage	5/1 - 9/10	132	0	0	0	0	1.96	4.45	7.83	7.11	1.47	0	0	0	22.82
Sorghum, Grain	5/20 - 10/5	138	0	0	0	0	0.47	3.59	7.64	6.43	3.15	0.23	0	0	21.51
Sugar Beets	4/28 - 10/17	172	0	0	0	0.07	2.10	4.64	7.91	8.26	5.46	1.54	0	0	29.98
Wheat, Winter	4/1 - 7/5	95	0	0	0	3.15	5.31	3.62	0.06	0	0	0	0	0	12.14
Average Precipitation			0.42	0.48	0.99	1.64	2.53	2.52	2.57	2.23	1.23	0.88	0.43	0.43	16.35
Effective Precipitation			0	0	0.27	1.14	1.91	2.19	2.42	1.99	0.98	0.34	0	0	11.28

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

CO683.50(b)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(b)
Byers, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/25 - 10/15	204	0	0	0.15	2.07	4.15	6.28	7.82	6.64	4.01	1.01	0	0	32.13
Pasture Grasses	4/1 - 10/25	208	0	0	0	1.73	3.44	5.11	6.48	5.68	3.53	1.48	0	0	27.45
Annuals															
Grain, Sorghum	5/14 - 10/5	144	0	0	0	0	0.72	3.65	7.23	5.86	2.79	0.21	0	0	20.46
Grain, Spring	4/1 - 7/20	110	0	0	0	1.13	4.38	5.75	1.23	0	0	0	0	0	12.49
	4/1 - 7/15	105													
Wheat, Winter	9/9 - 10/25	46	0	0	0	2.76	5.01	4.58	0.55	0	1.44	2.08	0	0	16.42
Average Precipitation			0.72	0.83	1.75	2.75	3.36	1.89	1.41	1.64	1.25	1.39	0.96	0.62	18.57
Effective Precipitation			0	0	0.41	1.75	2.34	1.59	1.31	1.41	0.94	0.60	0	0	10.39

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(c)
Canon City, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	2/27 - 12/10	287	0	0.02	1.22	2.63	4.82	6.96	8.42	7.16	4.55	2.61	1.11	0.19	39.69
Pasture Grasses	2/27 - 12/10	287	0	0.01	1.05	2.27	3.99	5.67	6.98	6.12	4.00	2.29	0.95	0.16	33.49
Annuals															
Corn, Silage	5/10 - 9/15	128	0	0	0	0	1.40	3.93	7.43	7.18	2.27	0	0	0	22.21
Orchards w/o cover	4/10 - 11/15	219	0	0	0	1.10	3.79	5.89	7.20	5.54	2.56	0.87	0.13	0	27.12
Spring Grain	3/25 - 7/15	122	0	0	0.08	1.83	5.41	5.48	0.69	0	0	0	0	0	13.51
Wheat, Winter	3/25 - 7/10 9/10 - 11/15	173	0	0	0.37	3.60	5.68	4.07	0.24	0	1.25	2.60	0.89	0	18.70
Average Precipitation			0.44	0.46	0.90	1.66	1.82	1.34	1.84	1.77	0.75	0.97	0.62	0.42	12.99
Effective Precipitation			0	0	0.58	1.13	1.40	1.18	1.72	1.55	0.57	0.69	0.39	0.05	9.28

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(d)

Cheyenne Wells, Colorado — TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/19 - 10/15	210	0	0	0.38	2.43	4.64	7.12	8.57	7.33	4.53	1.14	0	0	36.14
Pasture Grasses	3/19 - 11/10	236	0	0	0.33	2.10	3.84	5.80	7.11	6.27	3.99	2.08	0.22	0	31.74
Annuals															
Corn, Grain	5/5 - 10/4	152	0	0	0	0	1.75	4.33	7.77	7.83	4.34	0.29	0	0	25.81
Corn, Silage	5/5 - 9/5	123	0	0	0	0	1.73	4.48	7.96	7.20	0.74	0	0	0	22.11
Sugar Beets	4/28 - 10/15	170	0	0	0	0.07	2.17	4.77	8.07	8.48	5.49	1.38	0	0	30.43
	8/25 - 11/10	77													
Wheat, Winter	4/2 - 7/15	94	0	0	0	3.11	5.49	3.74	0.07	0.39	2.55	2.76	0.44	0	18.55
Average Precipitation			0.33	0.27	0.71	1.31	2.68	2.35	2.86	2.52	1.44	1.10	0.49	0.20	16.26
Effective Precipitation			0	0	0.17	0.93	2.03	2.08	2.68	2.24	1.14	0.37	0	0	11.68

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(e)
Colorado Springs, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/28 - 10/19	205	0	0	0.07	1.96	3.86	5.87	7.24	6.13	3.72	1.19	0	0	30.04
Pasture Grasses	3/28 - 11/5	222	0	0	0.06	1.69	3.20	4.78	6.00	5.24	3.27	1.71	0.09	0	26.04
Annuals															
Corn, Grain	5/15 - 10/8	146	0	0	0	0	0.85	3.16	6.15	6.18	3.66	0.49	0	0	20.49
Corn, Silage	5/15 - 9/15	123	0	0	0	0	0.84	3.14	6.23	6.15	1.86	0	0	0	18.22
Sorghum Grain	6/5 - 10/1	118	0	0	0	0	0	1.83	5.90	5.65	2.58	0.03	0	0	15.99
Wheat, Winter	4/12 - 7/15 9/1 - 10/25	94 58	0	0	0	1.61	4.67	3.47	0.06	0	1.95	2.30	0	0	14.06
Average Precipitation			0.31	0.34	0.77	1.45	2.12	2.31	3.10	2.58	1.11	0.92	0.45	0.27	15.73
Effective Precipitation			0	0	0.03	1.00	1.58	1.90	2.67	2.14	0.85	0.39	0	0	10.59

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

ble C0683.50(f)

rtez, Colorado

TR-21 Blaney Criddle Method

	Growing Season		Average Consumptive Use (inches of water)												
ROPS	Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
' rennials															
.lfalfa	3/23 - 11/6	259	0	0	0.23	1.88	3.61	5.47	6.83	5.79	3.59	1.85	0.11	0	29.36
'asture Grasses	3/23 - 11/6	228	0	0	0.20	1.63	2.99	4.45	5.66	4.95	3.15	1.62	0.09	0	24.74
.nnuals															
:orn, Silage	5/18 - 9/28	133	0	0	0	0	0.62	2.72	5.37	5.83	3.44	0	0	0	17.98
;rain, Spring	4/15 - 8/15	122	0	0	0	0.37	2.76	6.08	5.13	0.45	0	0	0	0	14.79
Wheat, Winter	9/5 - 8/15	334	0	0	0	1.30	4.46	6.15	4.41	0.36	1.64	1.81	0	0	20.13
Average Precipitation			1.04	0.82	1.02	1.05	0.94	0.54	1.14	1.60	1.16	1.54	0.84	1.21	12.90
Effective Precipitation			0	0	0.15	0.70	0.69	0.43	1.01	0.19	0.85	1.01	0.06	0	5.09

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(g)
Delta, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	3/12 - 10/14	216	0	0	0.73	2.61	4.83	6.81	8.25	6.81	4.29	1.00	0	0	35.33
Pasture Grasses	3/12 - 10/31	233	0	0	0.63	2.25	4.00	5.55	6.84	5.83	3.77	1.95	0	0	30.82
Annuals															
Corn, Grain	5/5 - 11/1	180	0	0	0	0	1.79	3.75	6.76	6.88	4.49	2.28	0.02	0	25.88
Corn, Silage	5/5 - 11/1	180	0	0	0	0	1.72	3.46	5.98	6.64	4.65	2.49	0.02	0	24.96
Orchards (w/ cover)	4/5 - 9/25	173	0	0	0	2.17	4.82	6.80	8.26	6.81	3.57	0	0	0	32.43
Orchards (w/o cover)	4/5 - 9/5	153	0	0	0	1.36	3.80	5.77	7.06	5.27	0.40	0	0	0	23.66
Small Vegetables	4/15 - 10/15	183	0	0	0	0.43	2.25	4.35	6.01	5.14	2.89	0.54	0	0	21.64
Spring Grain	4/5 - 8/10	127	0	0	0	1.05	4.37	7.58	4.93	0.21	0	0	0	0	18.14
Sugar Beets	4/15 - 10/20	188	0	0	0	0.61	2.53	5.00	8.03	7.91	5.23	1.74	0	0	31.05
Average Precipitation			0.43	0.43	0.50	0.69	0.64	0.66	0.65	1.21	0.83	0.95	0.47	0.43	7.89
Effective Precipitation			0	0	0.18	0.49	0.48	0.44	0.58	0.99	0.63	0.28	0	0	4.07

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

CO683.50(h)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(h)

Durango, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	3/27 - 11/7	225	0	0	0.10	1.83	3.40	4.90	6.44	5.47	3.39	1.81	0.15	0	27.49
Pasture Grasses	3/27 - 11/7	225	0	0	0.09	1.58	2.81	3.99	5.34	4.67	2.98	1.59	0.12	0	23.17
Annuals															
Corn, Silage	5/25 - 9/28	126	0	0	0	0	0.26	2.27	4.79	5.49	3.25	0	0	0	16.06
Spring Grain	4/30 - 9/10	133	0	0	0	0	1.63	4.51	7.22	3.26	0.11	0	0	0	16.73
Wheat, Winter	4/15 - 8/15 9/5 - 10/25	172	0	0	0	1.26	4.20	5.51	4.15	0.34	1.53	1.84	0	0	18.83
Average Precipitation			1.70	1.14	1.47	1.36	1.12	0.88	1.85	2.43	1.59	1.94	1.11	2.00	18.59
Effective Precipitation			0	0	0.09	0.89	0.80	0.69	1.54	1.86	1.12	1.20	0.10	0	8.34

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(i)

Fruita, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/13 - 10/16	217	0	0	0.68	2.61	4.88	6.97	8.56	7.04	4.34	1.13	0	0	36.22
Pasture Grasses	3/13 - 10/31	232	0	0	0.58	2.26	4.04	5.68	7.10	6.03	3.82	1.93	0	0	31.44
Annuals															
Beans, Dry	6/1 - 9/15	106	0	0	0	0	0	3.88	7.96	6.56	1.53	0	0	0	19.93
Corn, Grain	5/10 - 10/15	158	0	0	0	0	1.44	3.86	7.29	7.12	4.36	1.05	0	0	25.12
Corn, Silage	5/10 - 9/20	133	0	0	0	0	1.41	3.85	7.39	7.10	2.92	0	0	0	22.67
Grain, Spring	4/20 - 8/20	122	0	0	0	0.30	3.30	7.56	7.43	1.02	0	0	0	0	19.61
Orchard (w/ cover)	4/1 - 9/20	172	0	0	0	1.58	3.84	5.90	7.31	5.45	1.63	0	0	0	25.71
Small Vegetables	4/15 - 9/1	139	0	0	0	0.45	2.63	4.86	6.16	3.91	0.05	0	0	0	18.06
Sugar Beets	4/15 - 10/15	183	0	0	0	0.61	2.58	5.21	8.46	8.22	5.22	1.28	0	0	31.58
Wheat, Winter	3/20 - 7/10 9/1 - 11/1	112 61	0	0	0.66	3.56	5.67	3.88	0.24	0	2.20	2.71	0.03	0	18.95
Average Precipitation			0.68	0.53	0.70	0.77	0.54	0.56	0.58	1.13	0.75	0.84	0.62	0.60	8.30
Effective Precipitation			0	0	0.27	0.51	0.36	0.37	0.62	0.91	0.68	0.26	0	0	3.98

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(j)
Glenwood Springs, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/21 - 10/15	208	0	0	0.29	2.12	4.02	5.83	7.37	6.13	3.83	0.97	0	0	30.56
Pasture Grasses	3/21 - 10/27	220	0	0	0.25	1.83	3.33	4.75	6.11	5.24	3.37	1.54	0	0	26.42
Annuals															
Corn, Silage	5/15 - 9/15	123	0	0	0	0	0.87	3.12	6.34	6.15	1.92	0	0	0	18.40
Average Precipitation			1.80	1.75	1.53	1.90	1.36	1.19	1.36	1.67	1.41	1.40	1.21	1.45	18.03
Effective Precipitation			0	0	0.28	1.24	1.01	0.98	1.22	1.38	1.03	0.45	0	0	7.59

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(k)
Grand Junction, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa zone 1	3/12 - 11/4	237	0	0	0.74	2.58	5.15	7.69	9.35	7.59	4.65	2.43	0.10	0	40.28
Alfalfa zone 2	3/2 - 9/25	207	0	0	1.36	2.32	4.34	6.20	8.68	7.28	3.81	0	0	0	33.99
Grass, Pasture	3/2 - 11/3	246	0	0	1.17	2.01	3.59	5.05	7.20	6.23	4.02	2.02	0.06	0	31.35
Annuals															
Beans, Dry	6/1 - 9/15	106	0	0	0	0	0	4.29	8.70	7.07	1.64	0	0	0	21.70
Corn, Grain	5/1 - 9/15	137	0	0	0	0	1.97	4.32	8.28	6.95	2.07	0	0	0	23.59
Corn, Silage															
Grain, Spring	4/5 - 8/1	118	0	0	0	0.97	4.13	6.62	3.47	0	0	0	0	0	15.19
Orchard zone 1 (w/ cover)	4/1 - 10/10	192	0	0	0	2.50	5.14	7.68	9.36	7.59	4.64	0.78	0	0	37.69
Orchard zone 2 (w/o cover)	5/9 - 9/29	143	0	0	0	0	3.07	6.19	8.69	7.28	4.41	0	0	0	29.64
Small Vegetables	4/15 - 10/15	183	0	0	0	0.43	2.40	4.91	6.81	5.73	3.13	0.59	0	0	24.00
Sugar Beets	4/15 - 10/15	183	0	0	0	0.60	2.72	5.75	9.25	8.85	5.59	1.42	0	0	34.18
Wheat, Winter	4/5 - 8/1	118	0	0	0	2.66	5.33	6.16	2.86	0	0	0	0	0	17.01
Average Precipitation			0.64	0.61	0.75	0.79	0.63	0.55	0.46	1.05	0.84	0.93	0.61	0.55	8.41
Effective Precipitation			0	0	0.29	0.54	0.49	0.49	0.45	0.97	0.65	0.64	0.04	0	4.59

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(I)
Greeley, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	4/1 - 10/10	193	0	0	0	2.03	4.22	6.37	7.95	6.58	3.82	0.61	0	0	31.58
Pasture Grasses	4/5 - 10/16	194	0	0	0	1.51	3.49	5.19	6.60	5.62	3.36	0.86	0	0	26.63
Annuals															
Beans, Dry	5/20 - 9/2	105	0	0	0	0	0.75	4.57	7.78	5.17	0.15	0	0	0	18.42
Corn, Silage	4/30 - 9/16	139	0	0	0	0	1.89	3.97	7.26	6.59	2.03	0	0	0	21.74
Corn, Sweet	4/30 - 9/16	139	0	0	0	0	2.00	4.46	7.59	6.60	2.10	0	0	0	22.75
Grain Sorghum	5/20 - 10/2	135	0	0	0	0	0.44	3.33	7.23	5.80	2.61	0.07	0	0	19.48
Potatoes, Irish	4/20 - 9/20	153	0	0	0	0.25	1.88	4.96	8.98	8.44	3.63	0	0	0	28.14
Small Vegetables	4/7 - 9/8	154	0	0	0	0.60	2.44	4.47	5.77	3.99	0.43	0	0	0	17.70
Sugar Beets	4/7 - 10/7	183	0	0	0	0.77	2.47	5.18	8.23	7.70	4.46	0.50	0	0	29.31
Wheat, Winter	9/1 - 10/16 4/17 - 7/16	45 90	0	0	0	1.25	5.18	5.50	0.78	0	2.35	1.32	0	0	16.38
Average Precipitation			0.35	0.30	0.75	1.48	2.41	1.81	1.34	1.05	0.97	1.02	0.44	0.28	12.20
Effective Precipitation			0	0	0	0.95	1.73	1.51	1.25	0.91	0.72	0.22	0	0	7.32

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(m)

Gunnison, Colorado

TR-21 Blaney Criddle Meth

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOT
Perennials															
Alfalfa	4/16 - 9/7	144	0	0	0	0.60	2.71	4.24	5.35	4.47	0.62	0	0	0	17.
Pasture Grasses	4/16 - 10/8	175	0	0	0	0.52	2.24	3.46	4.44	3.82	2.35	0.29	0	0	17.
Average Precipitation			0.97	0.98	0.81	0.80	0.76	0.78	1.47	1.46	0.89	0.72	0.60	0.76	11
Effective Precipitation			0	0	0	0.24	0.52	0.59	1.18	1.11	0.14	0	0	0	[illegible]

Net irrigaiton requirement is the difference between crop consumpti
use and effective precipitation.

CO683.50(n)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(n)
Holly, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/10 - 10/20	224	0	0	0.87	2.76	5.18	7.79	9.09	7.65	4.95	1.65	0	0	39.34
Pasture Grasses	3/10 - 1/8	243	0	0	0.75	2.39	4.29	6.34	7.54	6.55	4.35	2.25	0.20	0	34.66
Annuals															
Corn, Grain	4/25 - 10/9	167	0	0	0	0.20	2.47	5.13	8.41	7.66	4.81	0.72	0	0	29.40
Corn, Silage	5/1 - 9/28	142	0	0	0	0	2.23	4.71	8.16	7.70	3.32	0	0	0	26.12
Grain Sorghum	5/10 - 10/9	152	0	0	0	0	1.15	4.75	8.45	6.82	3.55	0.48	0	0	25.20
Melons & Cantalopes	5/20 - 8/25	97	0	0	0	0	0.78	4.34	6.55	4.18	0	0	0	0	15.85
Small Vegetables	3/10 - 8/15	158	0	0	0.36	1.68	3.73	5.61	5.70	1.63	0	0	0	0	18.71
Sugar Beets	4/15 - 10/20	188	0	0	0	0.64	2.71	5.72	8.85	8.88	6.02	2.01	0	0	34.83
Wheat, Winter	9/1 - 7/5	307	0	0	0.59	3.77	5.92	3.61	0.06	0	2.36	2.94	0.40	0	19.65
Average Precipitation			0.49	0.37	0.77	1.35	2.53	2.26	2.33	2.34	1.09	0.91	0.53	0.36	15.33
Effective Precipitation			0	0	0.27	1.10	1.78	1.95	2.24	1.98	0.99	0.41	0	0	10.72

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(o)

Lamar, Colorado

TR-21 Blaney Criddle Metho

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOT
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/15 - 10/18	217	0	0	0.56	2.76	5.20	7.69	9.09	7.65	4.69	1.42	0	0	39.0
Pasture Grasses	3/15 - 11/15	245	0	0	0.48	2.39	4.31	6.26	7.54	6.55	4.13	2.15	0.35	0	34.1
Annuals															
Corn, Grain	5/5 - 10/19	167	0	0	0	0	1.88	4.16	7.37	7.71	4.93	0.76	0	0	26.8
Melons & Cantaloupes	5/20 - 8/25	97	0	0	0	0	0.78	4.29	6.55	4.18	0	0	0	0	15.8
Small Vegetables	3/1 - 8/15	167	0	0	0.48	1.83	3.81	5.51	5.61	1.61	0	0	0	0	18.8
Sorghum, Grain	5/25 - 10/9	137	0	0	0	0	0.28	3.47	7.87	7.10	3.46	0.46	0	0	22.6
Spring Grain	3/20 - 7/1	103	0	0	0.16	2.34	5.92	3.40	0	0	0	0	0	0	11.8
Sugar Beets	4/15 - 10/18	186	0	0	0	0.64	2.73	5.69	8.90	8.90	5.69	1.72	0	0	34.2
Wheat, Winter	9/1 - 11/15 3/27 - 7/5	75 100	0	0	0.22	3.78	6.05	3.77	0.07	0	2.12	2.62	0.67	0	19.3
Average Precipitation			0.49	0.37	0.77	1.35	2.53	2.26	2.33	2.34	1.09	0.91	0.53	0.36	15.
Effective Precipitation			0	0	0.26	0.97	1.99	2.07	2.29	2.13	0.88	0.37	0	0	11.

Net irrigaiton requirement is the difference between crop consumptiv use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

e C0683.50(n)

y, Colorado

TR-21 Blaney Criddle Method

	Growing Season		Average Consumptive Use (inches of water)												
PS	Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
ennials															
lfa	3/10 - 10/20	224	0	0	0.87	2.76	5.18	7.79	9.09	7.65	4.95	1.65	0	0	39.34
sture Grasses	3/10 - 1/8	243	0	0	0.75	2.39	4.29	6.34	7.54	6.55	4.35	2.25	0.20	0	34.66
nuals															
n, Grain	4/25 - 10/9	167	0	0	0	0.20	2.47	5.13	8.41	7.66	4.81	0.72	0	0	29.40
rn, Silage	5/1 - 9/28	142	0	0	0	0	2.23	4.71	8.16	7.70	3.32	0	0	0	26.12
ain Sorghum	5/10 - 10/9	152	0	0	0	0	1.15	4.75	8.45	6.82	3.55	0.48	0	0	25.20
lons & ntalopes	5/20 - 8/25	97	0	0	0	0	0.78	4.34	6.55	4.18	0	0	0	0	15.85
all egetables	3/10 - 8/15	158	0	0	0.36	1.68	3.73	5.61	5.70	1.63	0	0	0	0	18.71
gar Beets	4/15 - 10/20	188	0	0	0	0.64	2.71	5.72	8.85	8.88	6.02	2.01	0	0	34.83
heat, Winter	9/1 - 7/5	307	0	0	0.59	3.77	5.92	3.61	0.06	0	2.36	2.94	0.40	0	19.65
verage Precipitation			0.49	0.37	0.77	1.35	2.53	2.26	2.33	2.34	1.09	0.91	0.53	0.36	15.33
ffective Precipitation			0	0	0.27	1.10	1.78	1.95	2.24	1.98	0.99	0.41	0	0	10.72

et irrigaiton requirement is the difference between crop consumptive se and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(o)
Lamar, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/15 - 10/18	217	0	0	0.56	2.76	5.20	7.69	9.09	7.65	4.69	1.42	0	0	39.06
Pasture Grasses	3/15 - 11/15	245	0	0	0.48	2.39	4.31	6.26	7.54	6.55	4.13	2.15	0.35	0	34.16
Annuals															
Corn, Grain	5/5 - 10/19	167	0	0	0	0	1.88	4.16	7.37	7.71	4.93	0.76	0	0	26.81
Melons & Cantaloupes	5/20 - 8/25	97	0	0	0	0	0.78	4.29	6.55	4.18	0	0	0	0	15.80
Small Vegetables	3/1 - 8/15	167	0	0	0.48	1.83	3.81	5.51	5.61	1.61	0	0	0	0	18.85
Sorghum, Grain	5/25 - 10/9	137	0	0	0	0	0.28	3.47	7.87	7.10	3.46	0.46	0	0	22.64
Spring Grain	3/20 - 7/1	103	0	0	0.16	2.34	5.92	3.40	0	0	0	0	0	0	11.82
Sugar Beets	4/15 - 10/18	186	0	0	0	0.64	2.73	5.69	8.90	8.90	5.69	1.72	0	0	34.27
Wheat, Winter	9/1 - 11/15 3/27 - 7/5	75 100	0	0	0.22	3.78	6.05	3.77	0.07	0	2.12	2.62	0.67	0	19.30
Average Precipitation			0.49	0.37	0.77	1.35	2.53	2.26	2.33	2.34	1.09	0.91	0.53	0.36	15.33
Effective Precipitation			0	0	0.26	0.97	1.99	2.07	2.29	2.13	0.88	0.37	0	0	11.00

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

583.50(p)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

e C0683.50(p)

mont, Colorado

TR-21 Blaney Criddle Method

	Growing Season		Average Consumptive Use (inches of water)												
PS	Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
ennials															
alfa	3/25 - 10/12	201	0	0	0.16	2.05	4.03	6.14	7.52	6.40	3.85	0.76	0	0	30.91
ture Grasses	3/25 - 10/15	204	0	0	0.14	1.78	3.34	5.00	6.23	5.47	3.38	0.83	0	0	26.17
uals															
ans, Dry	5/1 - 8/10	101	0	0	0	0	2.41	5.72	6.40	1.30	0	0	0	0	15.83
n, Grain	5/1 - 9/20	142	0	0	0	0	1.82	4.17	7.12	6.20	2.35	0	0	0	21.66
n, Silage	5/5 - 9/10	128	0	0	0	0	1.49	3.75	6.88	6.36	1.26	0	0	0	19.74
ing Grain	4/1 - 7/15	105	0	0	0	1.15	4.35	5.10	0.66	0	0	0	0	0	11.36
gar Beets	4/15 - 9/15	153	0	0	0	0.48	2.32	5.18	8.09	7.29	2.12	0	0	0	25.48
ter Wheat	8/15 - 7/15	334	0	0	0	2.73	4.87	4.47	0.53	1.19	3.34	1.33	0	0	18.46
erage Precipitation			0.39	0.40	0.86	1.54	2.53	1.89	1.21	1.03	0.98	1.05	0.54	0.32	12.74
ective Precipitation			0	0	0.07	1.07	1.87	1.21	1.00	0.75	0.79	0.23	0	0	6.99

t irrigalton requirement is the difference between crop consumptive
e and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(q)
Meeker, Colorado
TR-21 Blaney Criddle Me

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
			Average Consumptive Use (inches of water)											
Perennials														
Alfalfa	3/23 - 9/23	184	0	0	0.26	1.53	2.95	4.47	6.44	5.43	2.47	0	0	0
Pasture Grasses	3/28 - 10/23	209	0	0	0.08	1.33	2.45	3.64	5.34	4.64	2.84	1.11	0	0
Annuals														
Corn, Silage	5/10 - 10/1	144	0	0	0	0	0.85	2.37	5.27	5.48	3.32	0.05	0	0
Spring Grain	4/15 - 9/1	139	0	0	0	0.29	2.06	4.78	6.44	1.89	0	0	0	0
Average Precipitation			1.22	1.15	1.43	1.72	1.43	1.49	1.47	1.95	1.24	1.52	1.14	1.30
Effective Precipitation			0	0	0.15	0.92	1.12	1.39	0.65	1.09	0.87	0	0	0

Net irrigaiton requirement is the difference between crop consumpt use and effective precipitation.

:0683.50(r)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

able C0683.50(r)

onte Vista, Colorado | TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
lfalfa	4/8 - 10/24	199	0	0	0	1.13	2.80	4.79	5.83	4.89	3.04	1.10	0	0	23.58
Pasture Grasses	4/8 - 10/24	199	0	0	0	0.98	2.32	3.90	4.83	4.91	2.67	0.96	0	0	19.85
Annuals															
Potatoes	5/20 - 9/10	113	0	0	0	0	0.33	2.54	6.09	6.24	1.29	0	0	0	16.49
Small Vegetables	4/15 - 7/15	91	0	0	0	0.30	1.82	3.32	1.35	0	0	0	0	0	6.79
Spring Grain	4/11 - 8/15	136	0	0	0	0.41	2.28	5.36	4.25	0.36	0	0	0	0	12.66
Average Precipitation			0.29	0.22	0.44	0.63	0.55	0.56	1.18	1.33	0.75	0.73	0.23	0.34	7.25
Effective Precipitation			0	0	0	0.29	0.37	0.42	0.96	1.02	0.52	0.35	0	0	3.93

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(s)

Norwood, Colorado — TR-21 Blaney Criddle Methoc

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOT.
Perennials															
Alfalfa	4/16 - 10/6	172	0	0	0	0.74	3.22	4.87	6.15	5.11	3.18	0.31	0	0	23.5
Pasture Grasses	4/16 - 10/19	186	0	0	0	0.64	2.67	3.96	5.10	4.37	2.79	0.87	0	0	20.4
Annuals															
Spring Grain	4/5 - 8/1	117	0	0	0	0.66	3.07	5.19	2.46	0	0	0	0	0	11.3
Average Precipitation			1.08	1.21	1.31	1.45	1.02	0.84	1.59	2.13	1.49	1.61	0.93	1.07	15.
Effective Precipitation			0	0	0	0.44	0.73	0.66	1.32	1.63	1.05	0.19	0	0	6.0

Net irrigaiton requirement is the difference between crop consumptiv use and effective precipitation.

.0683.50(t)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

able C0683.50(t)
cky Ford, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/15 - 10/18	217	0	0	0.59	2.77	5.06	7.42	8.66	7.31	4.56	1.38	0	0	37.75
Pasture Grasses	3/12 - 11/6	239	0	0	0.60	2.40	4.20	6.04	7.19	6.25	4.01	2.09	0.14	0	32.92
Annuals															
Corn, Grain	4/25 - 10/5	163	0	0	0	0.21	2.43	4.98	8.09	7.28	4.37	0.37	0	0	27.73
Corn, Silage	5/1 - 9/15	137	0	0	0	0	2.19	4.60	7.91	7.31	2.27	0	0	0	24.28
Corn, Sweet	5/1 - 8/15	106	0	0	0	0	2.46	6.15	8.35	3.41	0	0	0	0	20.37
Melons & Cantaloupes	5/20 - 8/25	97	0	0	0	0	0.76	4.14	6.24	3.99	0	0	0	0	15.13
Small Vegetables	3/15 - 9/15	184	0	0	0.22	1.43	3.37	5.31	6.25	4.60	1.05	0	0	0	22.23
Spring Grain	4/15 - 7/20	96	0	0	0	0.60	4.57	7.38	1.60	0	0	0	0	0	14.15
Sugar Beets	4/16 - 10/15	182	0	0	0	0.60	2.65	5.51	8.54	8.52	5.49	1.39	0	0	32.70
Average Precipitation			0.40	0.28	0.72	1.37	1.78	1.56	2.06	1.66	1.03	0.94	0.45	0.28	12.53
Effective Precipitation			0	0	0.24	0.98	1.44	1.45	2.01	1.53	0.83	0.39	0	0	8.89

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(u)
Salida, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	4/17 - 10/20	186	0	0	0	0.85	3.45	5.04	6.12	5.12	3.16	1.09	0	0	24.83
Pasture Grasses	4/17 - 10/20	186	0	0	0	0.74	2.86	4.10	5.08	4.38	2.78	0.96	0	0	20.90
Annuals															
Spring Grain	4/1 - 9/10	162	0	0	0	0.88	2.81	5.56	6.26	2.45	0.08	0	0	0	18.04
Average Precipitation			0.33	0.51	0.87	1.17	1.30	0.92	1.66	1.51	0.80	1.20	0.56	0.54	11.37
Effective Precipitation			0	0	0	0.33	0.94	0.73	1.37	1.19	0.57	0.51	0	0	5.66

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

C0683.50(v)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(v)
San Luis, Colorado
TR-21 Blaney Criddle Method

	Growing Season		Average Consumptive Use (inches of water)												
CROPS	Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	4/9 - 10/27	201	0	0	0	1.02	2.85	4.43	5.33	4.56	2.85	1.23	0	0	22.27
Pasture Grasses	4/9 - 10/27	201	0	0	0	0.89	2.36	3.61	4.42	3.90	2.51	1.08	0	0	18.77
Annuals															
Potatoes	5/20 - 9/10	113	0	0	0	0	0.34	2.35	5.57	5.81	1.21	0	0	0	15.28
Spring Grain	4/11 - 8/15	126	0	0	0	0.39	2.32	4.96	3.88	0.34	0	0	0	0	11.89
Average Precipitation			0.40	0.50	0.70	0.90	1.10	0.80	2.20	1.60	1.10	1.00	0.40	0.60	11.30
Effective Precipitation			0	0	0	0.41	0.77	0.61	1.69	1.21	0.77	0.56	0	0	6.05

'et irrigaiton requirement is the difference between crop consumptive
ıse and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(w)

Springfield, Colorado

TR-21 Blaney Criddle Metho'

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	3/15 - 10/20	219	0	0	0.54	2.61	4.79	7.45	8.44	7.24	4.73	1.64	0	0	37.4
Pasture Grasses	3/15 - 11/20	240	0	0	0.46	2.26	3.97	6.07	7.00	6.20	4.16	2.24	0.25	0	32.6
Annuals															
Corn, Grain	5/5 - 10/13	161	0	0	0	0	1.80	4.37	7.44	7.31	4.70	1.05	0	0	26.6
Sorghum, Grain	5/20 - 10/13	146	0	0	0	0	0.50	3.68	7.44	6.75	3.58	0.70	0	0	22.6
Spring Grain	4/20 - 7/5	76	0	0	0	0.35	4.45	5.54	0.10	0	0	0	0	0	10.4
Sugar Beets	4/20 - 10/20	183	0	0	0	0.40	2.39	5.26	8.08	8.38	5.77	2.00	0	0	32.2
Wheat, Winter	9/1 - 11/10 3/25 - 7/5	70 102	0	0	0.32	3.57	5.54	3.57	0.06	0	2.22	2.87	0.49	0	18.6
Average Precipitation			0.44	0.34	0.87	1.26	2.50	2.31	2.71	2.04	1.14	0.86	0.51	0.38	15..
Effective Precipitation			0	0	0.29	0.90	1.92	2.08	2.54	1.84	0.92	0.39	0	0	10.'

Net irrigaiton requirement is the difference between crop consumptiv use and effective precipitation.

0683.50(x)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

able C0683.50(x)
'erling, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/20 - 10/10	204	0	0	0.32	2.46	4.73	7.03	8.55	7.21	4.23	0.71	0	0	35.24
Pasture Grasses	3/24 - 10/30	220	0	0	0.16	1.86	3.44	5.25	6.58	5.65	3.42	1.65	0	0	28.01
Annuals															
Beans, Dry	6/1 - 9/5	96	0	0	0	0	0	4.05	8.15	6.10	0.45	0	0	0	18.75
Corn, Silage	5/5 - 9/5	123	0	0	0	0	1.54	4.06	7.38	6.48	0.63	0	0	0	20.09
Spring Grain	4/10 - 7/30	111	0	0	0	0.66	3.77	6.90	2.96	0	0	0	0	0	14.29
Sugar Beets	4/25 - 10/10	168	0	0	0	0.18	2.29	4.94	8.30	8.40	5.04	0.84	0	0	29.99
Wheat, Winter	4/15 - 7/1 9/10 - 10/15	77 35	0	0	0	1.46	5.12	3.26	0	0	1.48	1.21	0	0	12.53
Average Precipitation			0.31	0.35	0.79	1.89	2.52	2.28	1.65	1.85	1.30	0.98	0.47	0.47	14.92
Effective Precipitation			0	0	0.06	0.89	1.29	1.34	1.09	1.12	0.69	0.16	0	0	6.68

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table C0683.50(y)
Trinidad, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
Perennials															
Alfalfa	3/10 - 11/8	243	0	0	0.79	2.23	4.00	6.33	7.08	6.52	3.60	2.51	0.19	0	33.2
Pasture Grasses	3/10 - 11/8	243	0	0	0.68	1.93	3.32	5.16	5.87	5.57	3.17	2.21	0.16	0	28.1
Annuals															
Corn, Grain	5/13 - 10/8	148	0	0	0	0	1.01	3.48	6.09	6.56	3.53	0.63	0	0	21.3
Corn Silage	5/10 - 9/1	114	0	0	0	0	1.29	3.98	7.27	6.48	0.13	0	0	0	19.1
Wheat, Winter	3/26 - 7/20 9/10 - 10/3	116 23	0	0	0.30	3.05	4.83	4.91	0.83	0	1.87	0.35	0	0	16.1
Average Precipitation			0.38	0.41	0.80	1.31	1.85	1.46	1.86	1.91	0.97	0.90	0.45	0.50	12.
Effective Precipitation			0	0	0.34	0.87	1.33	1.21	1.58	1.57	0.70	0.61	0.05	0	8.

Net irrigaiton requirement is the difference between crop consumptiv use and effective precipitation.

CO683.50(z)

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(z)
Wray, Colorado

TR-21 Blaney Criddle Method

CROPS	Growing Season Average Dates	Days	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTAL
			Average Consumptive Use (inches of water)												
Perennials															
Alfalfa	3/20 - 10/10	204	0	0	0.32	2.46	4.73	7.03	8.55	7.21	4.23	0.71	0	0	35.24
Pasture Grasses	3/20 - 10/30	224	0	0	0.28	2.13	3.92	5.73	7.09	6.17	3.72	1.88	0	0	30.92
Annuals															
Beans, Dry	6/1 - 9/5	96	0	0	0	0	0	4.05	8.15	6.10	0.45	0	0	0	18.75
Corn, Grain	5/5 - 10/5	153	0	0	0	0	1.79	4.26	7.73	7.22	4.08	0.34	0	0	25.42
Grain, Sorghum	6/1 - 9/1	92	0	0	0	0	0	3.22	7.79	5.00	0.08	0	0	0	16.09
Soybeans	5/25 - 10/5	133	0	0	0	0	0.17	1.88	4.18	6.29	3.62	0.27	0	0	16.41
Spring Grain	4/1 - 7/25	115	0	0	0	1.31	4.87	6.91	2.08	0	0	0	0	0	15.17
Sugar Beets	4/25 - 10/10	168	0	0	0	0.18	2.29	4.94	8.30	8.40	5.04	0.84	0	0	29.99
Average Precipitation			0.41	0.36	0.87	1.89	3.16	3.13	2.91	2.43	1.47	1.01	0.49	0.38	18.51
Effective Precipitation			0	0	0.18	1.29	2.32	2.61	2.67	2.11	1.12	0.22	0	0	12.56

Net irrigaiton requirement is the difference between crop consumptive use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

Table CO683.50(aa)
Walden, Colorado
TR-21 Blaney Criddle Meth

CROPS	Growing Season Average Dates	Days	Average Consumptive Use (inches of water) Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	TOTA
Perennials															
Alfalfa	4/30 - 9/19	111	0	0	0	0	2.25	3.64	4.69	2.31	0	0	0	0	12.8
Pasture Grasses	4/30 - 9/27	150	0	0	0	0	1.86	2.96	3.89	3.22	1.68	0	0	0	13.6
Average Precipitation			0.51	0.42	0.50	0.72	1.02	1.11	1.24	1.29	1.01	0.71	0.54	0.49	9.
Effective Precipitation			0	0	0	0	0.69	0.79	0.96	0.58	0	0	0	0	3.

Net irrigaiton requirement is the difference between crop consumpti
use and effective precipitation.

ESTIMATED SEASONAL AND MONTHLY CONSUMPTIVE USE OF CROPS

able C0683.51 Peak period average daily consumptive use related to estimated monthly use.

Net Irrigation Application I (inches)	Computed Monthly Consumptive Use Rate (u_m) in inches 1/																
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
	Average Daily Use Rate (U_p) in inches per Day																
1.0	.15	.18	.20	.22	.24	.26	.28	.31	.33	.35	.37	.40	.42	.44	.46	.49	.51
1.5	.15	.17	.19	.21	.23	.25	.27	.29	.32	.34	.36	.38	.41	.43	.45	.47	.50
2.0	.15	.16	.18	.20	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.44	.46	.48
2.5	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	.36	.39	.41	.43	.45	.47
3.0	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44	.46
3.5	.14	.16	.18	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.44	.46
4.0	.14	.15	.17	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.43	.45
4.5	.14	.15	.17	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.43	.45
5.0	.13	.15	.17	.19	.21	.23	.25	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44
5.5	.13	.15	.17	.19	.21	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44
6.0	.13	.15	.17	.19	.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.41	.43

1/ Based on the formula $U_p = 0.034u_m^{1.09} I^{-.09}$ where

U_p = Average perak period consumptive use in inches.
U_m = Average consumptive use for the month in inches.
I = Net irrigaiton application in inches.

C0683.52 Recommended design use rates.
Peak consumptive use - inches/day.

(a) Climatic Zone 1 - (Location: Holly)

Crop	Net Irrigation Application 1"	2"	3"	4"	5"
Alfalfa	.37	.35	.34	.33	.32
Beets, sugar	.37	.35	.34	.33	.32
Corn, grain	.35	.33	.32	.31	.30
Corn, silage	.33	.31	.30	.29	.28
Grasses, pasture	.31	.29	.28	.27	.26
Melons & cantaloupes	.26	.25	.24	.23	.23
Sorghum, grain	.35	.33	.32	.31	.30
Vegetables, small	.23	.21	.21	.20	.20
Wheat, winter	.24	.23	.22	.21	.21

(b) Climatic Zone 2 - (Location: Delta)

Crop	Net Irrigation Application 1"	2"	3"	4"	5"
Alfalfa	.34	.32	.31	.30	.29
Beans, Dry	.32	.30	.23	.28	.27
Beets, sugar	.33	.31	.30	.29	.28
Corn, grain	.28	.27	.26	.25	.25
Corn silage	.27	.26	.25	.24	.24
Grain, spring	.31	.29	.28	.27	.26
Grasses, Pasture	.28	.27	.26	.25	.25
Orchard, with cover	.34	.32	.31	.30	.29
Orchard, without cover	.28	.27	.26	.25	.25
Vegetable, small	.24	.23	.22	.21	.21

(c) Climatic Zone 3 - (Location: Longmont)

Crops	Net Irrigation Application 1"	2"	3"	4"	5"
Alfalfa	.31	.29	.28	.27	.26
Beans, dry	.26	.25	.24	.23	.23
Beets, sugar	.33	.31	.30	.29	.28
Corn, grain	.28	.27	.26	.25	.25
Corn, silage	.28	.27	.26	.25	.25
Grain, spring	.20	.18	.18	.17	.17
Grasses, pasture	.25	.23	.22	.21	.21
Wheat, winter	.20	.18	.18	.17	.17

C0683.52(d)

(d) Climatic Zone 4 - (Location: Cortez)

Crops	Net Irrigation Application 1"	2"	3"	4"	5"
Alfalfa	.28	.27	.26	.25	.25
Corn, silage	.24	.23	.22	.21	.21
Grain, spring	.24	.23	.22	.21	.21
Grasses, pasture	.23	.21	.21	.20	.20
Wheat, winter	.25	.23	.22	.21	.21

(e) Climatic Zone 5 - (Location: Meeker)

Crop	Net Irrigation Application 1"	2"	3"	4"	5"
Alfalfa	.26	.25	.24	.23	.23
Corn, grain	.22	.20	.20	.19	.19
Corn, silage	.22	.20	.20	.19	.19
Grain, spring	.26	.25	.24	.23	.23
Grasses, pasture	.21	.19	.19	.18	.18
Wheat, winter	.20	.18	.18	.17	.17

(f) Climatic Zone 6 - (Location: Monte Vista)

Crop	Net Irrigation Application 1"	2"	3"	4"	5"
Alfalfa	.24	.23	.22	.21	.21
Grain, spring	.22	.20	.20	.19	.19
Grasses, pasture	.20	.18	.18	.17	.17
Potatoes	.24	.23	.22	.21	.21
Vegetables, small	.12	.11	.10	.10	.10

(g) Climatic Zone 7 - (Location: Walden)

Crop	Net Irrigation Application 1"	2"	3"	4"	5"
Alfalfa	.19	.17	.17	.16	.16
Grasses, pasture	.15	.15	.14	.14	.13

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Part 684 - Irrigation Methods Selection

Part 684 - Irrigation Methods Selection

SUBPART A - GENERAL

C0684.1 Irrigation methods.

(a) Irrigation water application is commonly designated according to the manner in which water is applied to the soil. There are four basic methods of applying water.

(1) Sprinkler irrigation--the soil surface is wetted much as it is by rainfall. There are many types of sprinklers such as pivot, sideroll, portable etc. These may be high pressure or the more common low pressure systems.

(2) Surface irrigation--water is applied by complete flooding such as borders or in furrows, whereby only part of the surface is wetted. The manner of applying surface water includes cablegation and surge systems.

(3) Subirrigation--water is applied beneath the surface through a rather porous subsoil or buried drip tubing, wetting the surface little if at all.

(4) Trickle irrigation--a form of surface system where only a portion of the surface is irrigated with filtered water applied as a micro-jet spray above the soil surface or below the soil surface through an extensive pipe system to each individual plant.

(b) Methods of applying irrigation water vary with topography, soil conditions, amount of land preparation that is practical, crops to be grown, value of the crops, cultural practices, and available water supply. Each method has its own limitations. Most can be adapted to a fairly wide range of conditions. At some sites, several methods of water application are suitable. On other sites, only one method can be used. Some farmers are accustomed to particular methods of applying water and will continue to use them even though others are more desirable and economical. Sound planning must consider the cost, ease of installation, maintenance required, and labor and skill required for operation of each suitable application method. To achieve acceptable irrigation efficiency, skill of the operator and flexibility of the system must be considered along with the irrigator's wishes, in selecting the best method of applying water.

C0684.2 Advantages and limitations.

(a) Table C0684.1 is a listing of the factors affecting water application methods. The adaptability, advantages and limitations of irrigation methods applicable to Colorado are contained in National Engineering Handbook, Section 15, Irrigation, Chapter 3, Planning Farm Irrigation Systems. Information on methods not discussed in NEH-15 will be included herein as needed.

Table C0684.1 Factors affecting the selection of a water-application method.

Water Application Method	Factors Affecting Selection			
	Land Slope	Water Intake Rate of the Soil	Water Tolerance of Crops	Wind Action
Sprinkler	Adaptable to both level and sloping ground surfaces.	Adaptable to any soil intake rates.	Adaptable to most all crops. May help promote fungi and disease on foilage and fruit.	Wind may affect application efficiency.
Surface	Land area must be leveled or graded to limited slopes or contours (0 to 1.0 percent slopes for most systems). It sometimes is possible to flood slightly steeper slopes that are sodded.	Not generally recommended for soils with high intake rates of more than 2.5 inches per hour or with extremely low intake rates such as peats and mucks.	Adaptable to most crops. May be harmful to root crops and to plants that cannot tolerate water standing on roots.	High winds may affect the application efficiency on bare soil. Usually not considered a factor.
Trickle	Adaptable to all land slopes.	Adaptable to all intake rates.	No problems.	No effect.
Below-surface Subirrigation	Land area should be level or contoured.	Adaptable only to those soils which have an impervious layer below the root zone, or a high controllable water table.	Adaptable to most all crops.	No effect.
Subsurface irrigation	Land area must be level or graded to limit slopes.	Adaptable only to medium to fine textured soils with moderate to good capillary movement.	No problems.	No effect.

C0684.3 Adapted methods.

(a) The individual irrigation methods are discussed in detail in Part 685, Irrigation Methods and Design Criteria. This part will briefly compare the different methods, and discuss their adaptability for various crops, soils, and land slopes. Table C0684.2 presents this information in tabular form.

(1) Column 1 - Locally Adapted Crops--Lists the major commercially important crops grown in Colorado. Crops not shown can be compared to those listed for irrigation adaptability.

(2) Column 2 - Spacings--Furrow spacings shown are normally used for the various crops. Changes in spacing will require modification of stream sizes and irrigation times. Corrugation spacing normally varies from 18 to 24 inches, depending upon the soil texture and desired net irrigation application. Subpart C, of Part 685 discusses determination of values for furrows and corrugations as used in this column.

(3) Column 3 - Moisture Extraction Depth--The depth from which mature crops, when properly irrigated, extract water from deep soil. Consideration must be given to soil limitations.

(4) Column 4 - Management Allowed Depletion (MAD)--The percentage of the available water which can be depleted prior to irrigation of the listed crop. The 50% level is adequate for most crops.

(5) Column 5 - Net Irrigation Application--The normal range of net irrigation water to apply to refill the root zone. The value is based on irrigating when 50% of the available moisture has been removed from the root zone by the crop, except for potatoes and peas. Potatoes are irrigated when 33% of the available moisture has been used; peas, when 40% has been used. A normal moisture extraction pattern is assumed.

(i) The value in this column is obtained by multiplying the minimum moisture holding capacity of the soil by the percent depletion allowed and the moisture extraction depth for mature plants.

(6) Column 6 - Adapted Irrigation Method--The suitability of each irrigation method to the crop is shown.

(i) Borders--Level and Graded are used with close growing crops such as grain, alfalfa, and grass. They are used on soils in the 0.1 to 2.0 intake families and slopes ranging from 0 to 3%. The maximum length of run is normally limited to 1300 feet. The system is adaptable to automation. They generally require large stream sizes on uniform grades.

C0684.3(a)(6)(ii)

(ii) Corrugations--Are used to direct the path of water in flood irrigation. They are used in close growing crops on slopes to 4%. They may be used in conjunction with other irrigation systems such as borders, contour ditches, etc. Length of run should not exceed 800 feet.

(iii) Contour Ditches--Are used to irrigated close growing crops such as grain, alfalfa, or grass. These ditches are normally installed about 300 feet apart, on a 0.4% ditch grade or flatter. The irrigation efficiency is low and the labor requirements can be high.

(iv) Furrow--The most common irrigation method in the State. They are adaptable on all soils to 4% slope. A variable land slope can be tolerated. Length of run should not exceed 2600 feet.

(v) Sprinklers--Are used for all types of crops on most soil types on a farmable slope. Very small streams of water can be used effectively. The major drawback is the initial investment and pumping costs are very high.

Table C0684.2 Crop Adaptations.

(1)	(2)	(3)	(4)	(5)	(6)					
LOCALLY ADAPTED CROPS	FURROW & CORR. SPACING (inches)	MOIST EXTRACTION DEPTH (feet)	MGMT ALLOWED DEFICIENCY % 2/	NORMAL NET IRRIG. APPLICATION 3/ (inches)	ADAPTED IRRIG. METHODS					REMARKS
					BORDERS	CORRUGATIONS	CONTOUR DITCH	FURROW	SPRINKLER	
Alfalfa & Sweet Clover	24	6	50	3 to 6	X	X	X		X	
Beans	22	3	50	1.5 to 3				X	X	
1/Corn & Sorghum	36	4	50	2 to 4	X			X	X	
Grass	18	3	50	1.5 to 3	X	X	X		X	
Peas	22	3	40	1.5 to 3				X	X	
Potatoes	36	3	33	1 to 2.5				X	X	
Small Grain	18	3	50	1.5 to 3	X	X	X		X	
Sugar Beets	22	4	50	2 to 4				X	X	

1/ May be furrows within borders.
2/ This is the same as the percent of depletion allowed from the available water capacity.
3/ Amount of water applied per irrigation depends upon soil type as well as method of application.

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Part 685 - Irrigation Methods and Design Criteria

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Part 685 - Irrigation Methods and Design Criteria

SUBPART A - GENERAL

C0685.1 Design criteria and standards.

(a) This section deals with the selection, suitability, advantages, limitations, design criteria, evaluations and adjustments for each type of irrigation.

(b) This section contains information needed to make adjustments and apply new technical knowledge.

(c) Design criteria for each of the methods of irrigation water application are contained in the appropriate chapters of Section 15 of the National Engineering Handbook. Design criteria and examples of irrigation methods most common to Colorado are included in this guide.

(d) Standards and Specifications for irrigation practices are contained in Section IV of the local Field Office Technical Guide.

C0685.2 Use of Design criteria.

Soil intake rates are known to vary throughout an irrigation season and from season to season. Therefore, an irrigation guide's value is only in giving general guidance for layout and operation of an irrigation system. Operational adjustments must then be made for differences in factors such as intake rates, net application depth and flow rates.

Part 685 - Irrigation Methods and Design Criteria

SUBPART B - BORDER IRRIGATION

C0685.10 General design considerations.

(a) Border irrigation is a method of controlled surface flooding. The field to be irrigated is divided into small strips by constructing parallel borders or dikes oriented in the direction of irrigation. Each strip is then irrigated separately by introducing water at one end. Two kinds of border irrigation--level and graded--are used depending on topography, soil, water supply, and other factors.

(b) Border irrigation is suited for all crops that are not damaged by short periods of inundation. It is used where conditions permit a high degree of water control. It is best suited to soils whose intake rates are neither low nor extremely high.

(c) In addition to the limits imposed by the hydraulic factors associated with level and graded border irrigation, designs also may be limited by practical layout and construction considerations. These limits are not mandatory requirements, but are good guides for design. They should be exceeded with caution and supported by field data.

(d) Soil Intake Characteristics and Intake Opportunity Time. All designs for the border method of water application depend on a knowledge of the intake characteristics of the soils in the design area. Each soil has its own intake characteristics, but the differences between some soils are so minor that for practical purposes several can be considered together. Experience indicates that all soils can be placed in one of eight intake families, thus greatly simplifying design procedure. Figure C0685.1 shows the general range of intake rate for each family, and Table C0685.60 shows the minimum intake opportunity time for various net depths of application for each intake family.

(e) Border strip width. Border strip widths are dependent upon the irrigation stream available, the amount of cross slope, and the accuracy of the land leveling in relation to the normal depths of flow to be expected. The width of the border strips must permit efficient operation of farm equipment. Some equipment, such as mowers and rakes, will tolerate a small amount of overlap on passes. Other equipment, such as a plow, seeder, and cultivator, is less flexible and requires a definite width for each pass. The minimum width of the border strip should accommodate at least one pass by the most restrictive type of equipment.

C0685.10(e)(1)

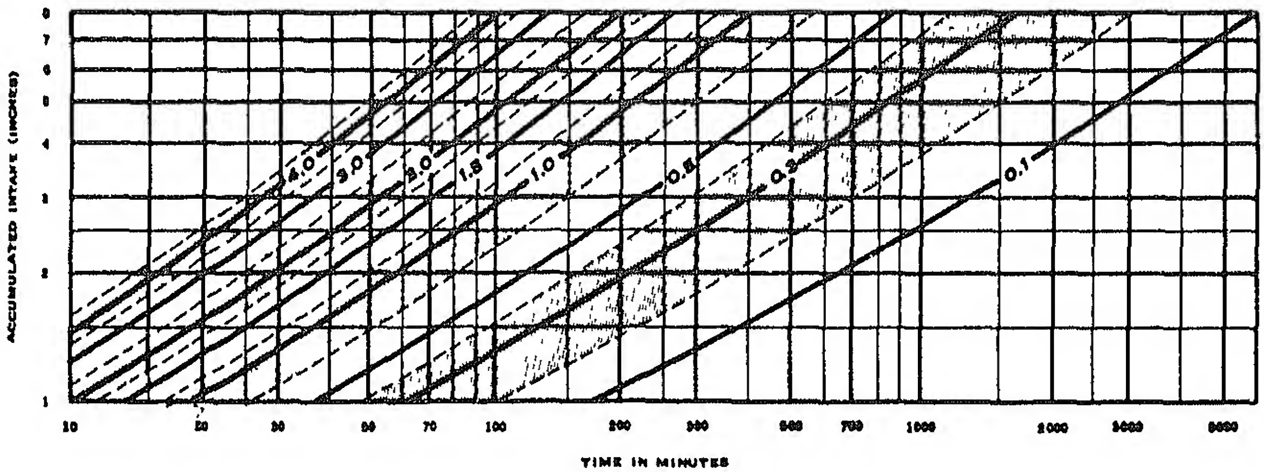


Figure C0685.1 Intake Families for Border Irrigation Design

(1) A width of about 15 feet is the practical minimum for hay and grain fields. Narrower strips are satisfactory for pastures. Where row crops are grown on border strips, the strips should be at least wide enough to allow for two passes with four-row equipment.

(2) Maximum widths are largely influenced by the difficulties in keeping the water uniformly spread over the strip width. Under normal construction procedures, wide border strips have greater cross slope elevation differences than narrower strips. As flow depths decrease because of increased slope, minor irregularities in the border strip surface may result in incomplete water coverage. For this reason, border strip widths should be reduced as irrigation grades are increased. Table C0685.1 lists the maximum border strip widths usually found acceptable.

Table C0685.1 Maximum Border Widths for Various Slopes.

Irrigation Grade Percent	ft/ft	Maximum Strip Width (ft)
Level	<.0005	200
0.05 - 0.1	.0005 - .001	120
0.11 - 0.5	.0011 - .005	60
0.51 - 1.0	.0051 - .01	50
1.01 - 2.0	.0101 - .02	40
2.01 - 4.0	.0201 - .04	30
4.01 - 6.0	.0401 - .06	20

(f) Ridge Height. Border ridges should be built so that the settled height is at least equal to or greater than:

(1) The design gross depth of application, or

(2) The design maximum depth of flow plus 0.15 feet.

(g) Depth of Flow. The flow at the upper end must not exceed some practical depth related to the construction and maintenance of the border ridges. The upper limit is generally considered to be six inches. Greater depths may be practical under some special conditions. Level borders can accommodate depths as great as eight or ten inches, but seldom should depths greater than this be considered. Depth of flow in graded borders is directly related to velocity.

(h) Roughness Coefficients. Mannings equation forms the basis for the equations used in the design of border irrigation systems. The roughness coefficient "n" is one of the important parameters in the equation. This coefficient is an expression of the flow retardance effects of the hydraulic boundary. Height, density, shape and stem stiffness of plants are some factors that effect retardance.

(1) More studies are needed to adequately define the proper value of "n" for different crops, stages of growth, and degrees of roughness of the soil surface. Table C0685.61 shows recommended coefficient of roughness values (n) for irrigation design.

(2) If design is limited by a maximum allowable flow depth, a conservatively high value of "n" should be used. On the other hand, if the design is limited by a minimum allowable stream size, a conservatively low "n" value should be used.

(i) Use of End Blocks. End blocks impound water on a border strip that might otherwise be lost to tailwater. This results in higher application efficiencies, provided the impounded area is of a significant size. For end blocks to be effective, the net depth of application must be greater than five percent of the total fall in the length of the border strip.

(1) Drainage must be considered when the depth of impoundment exceeds one and one-half times the depth of the net application.

(2) The distance that border strips can be lengthened by using end blocks has limitations. See page 4-39, Chapter 4 of NEH 15, Irrigation, for changes in design that can be made when end blocks are used.

C0685.10(j)

(j) Border Strip Length. Long border strips are easier to farm than are shorter lengths because they require fewer turns for farm equipment. However, factors other than flow hydraulics may determine the maximum lengths of run in specific fields. Changes in soils and in land slopes are other factors that may limit lengths. Field experience has indicated, however, that lengths of run in excess of a quarter mile seldom are satisfactory, even though half mile runs in some areas are being irrigated with success.

C0685.11 Level borders or basins.

(a) Level border irrigation is a ponding method of water application, where irrigation water is applied to a border strip faster than the soil intake rate. When the total amount of water has been applied, the irrigation stream is stopped and the water is allowed to pond on the soil surface. Since the level border has no grade and is closed at the ends the water will remain ponded until it is absorbed. Stream sizes though not critical must be sufficient to provide coverage of the entire strip in a relatively small portion of the time required for the soil to absorb the applied water.

(b) This kind of irrigation is best suited to soils with moderate to low intake rates (1.5 intake family or less). It is the best way to water soils with an extremely low intake rate, provided the crops can tolerate submergence for the time required for the water to enter the soil.

(c) Studies of curves showing the distribution of intake under various rates of advance have shown that a satisfactory irrigation will be accomplished if the following conditions are met:

(1) The volume of water delivered to the border strip is adequate to cover the area of the border strip to an average depth equal to the gross irrigation application.

(2) The intake opportunity time at the last point in the border strip covered is equal to the time required for the net irrigation to enter the soil.

(3) The longest intake opportunity time at any point on the border strip is such that detrimental deep percolation does not occur.

(4) The depth of flow is not greater than can be contained by the border ridges.

The first condition refers to the gross application; the second condition depends on the net application. The difference is equal to the deep percolation assuming no surface runoff or evaporation occurs.

(d) Design efficiencies. To avoid excessive deep percolation, design efficiencies should not be less than about 70 percent. This can usually be accomplished when the time required to cover the border strip is not more than 60 percent of the time required for the net application to enter the soil. Design efficiencies less than 70 percent should be considered only on soils with excellent internal drainage. On sites where irrigation water supply is limited or costly, or where crops may be damaged by prolonged flooding, design efficiencies in excess of 90 percent often are practical.

(1) Attainable application efficiencies are dependent upon several factors including surface uniformity and roughness of the field, type of crop and the stage of growth. Application efficiency is also related to soil intake characteristics and the depth of water applied. Table C0685.62 lists recommended design efficiencies for various net applications and intake families. These values also allow for reasonable variations caused by other factors. Adjustments should be made in the border system if the achieved efficiency is more than 20 percent below the recommended design efficiency.

(e) Border ridge height. The construction and maintenance of border ridges is very important in level border irrigation. In order to keep the ridge height within practical construction limits the flow depth at the head end of the border strip should be kept under six inches. Greater depths may be practical under special conditions, but depths of flow in excess of eight or ten inches seldom should be considered.

(1) Table C0685.2 can be used to estimate the advance time (T_t) to be expected in level borders.

(2) Figure C0685.2 can be used to estimate depth of flow expected in level borders. This chart is a graphical solution for a Manning Coefficient of Roughness (n) equal to 0.15. Depth of flow associated with other values of "n" can be determined by multiplying the values obtained from the chart by the appropriate conversion factors shown in the upper left corner of the chart. Note that the graph does not use unit stream values but uses Q_u = border length in 100's of feet times q, where q = stream size for each 100 feet of border strip one foot wide.

C0685.11(e)(2)

Table C0685.2 Ratio of T_t to T_n for various efficiency values

Efficiency	T_t/T_n				
Percent	Roughness Coefficient "n"				
	.04	.10	.15	.20	.25
95	0.10	0.14	0.16	0.18	0.19
90	0.17	0.24	0.28	0.31	0.34
85	0.24	0.34	0.40	0.45	0.48
80	0.35	0.50	0.58	0.65	0.70
75	0.49	0.69	0.80	0.89	0.97
70	0.66	0.93	1.08	1.20	1.31
65	0.88	1.25	1.45	1.62	1.76
60	1.16	1.63	1.90	2.12	2.30
55	1.49	2.10	2.45	2.73	2.97
50	1.95	2.75	3.20	3.56	3.88

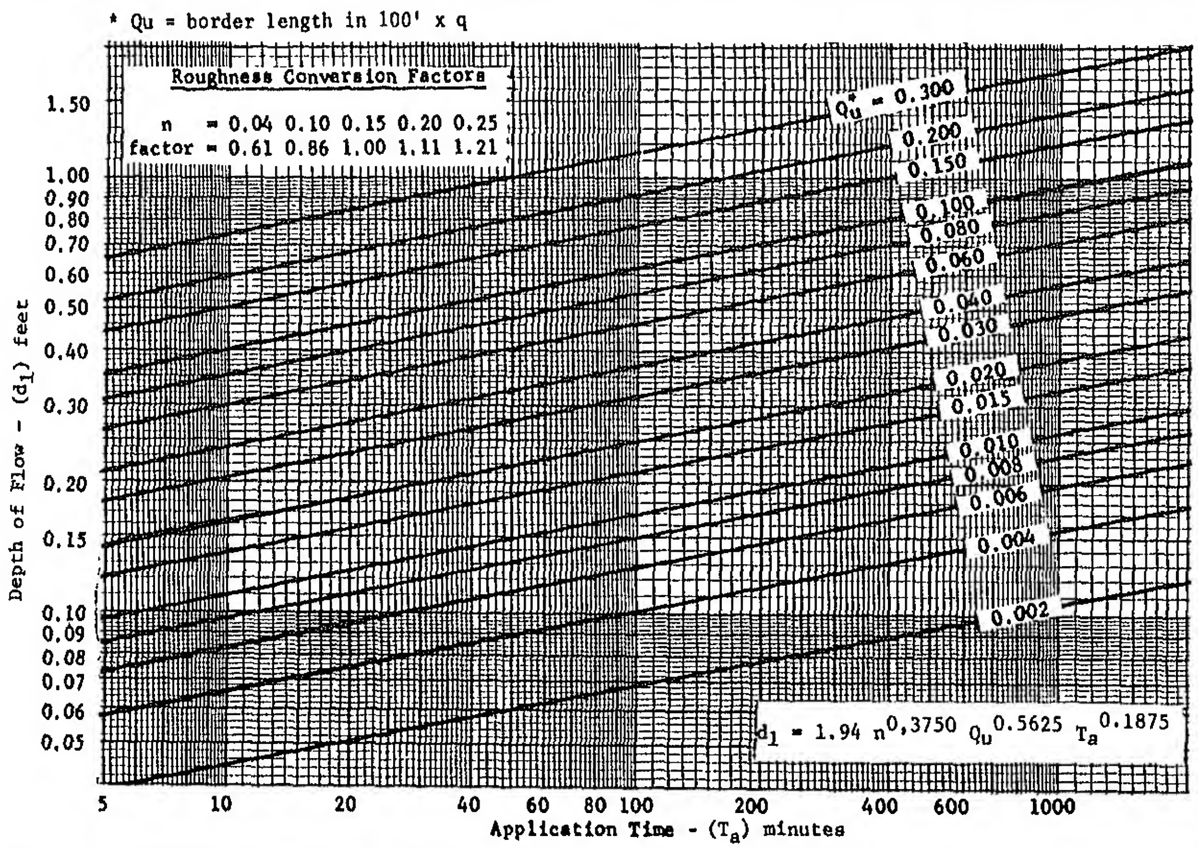


Figure C0685.2 Chart for estimating depth of flow in level basins with "n" of 0.15

(3) If the time of application (T_a) exceeds the time of advance (T_t), the water depth of the border strip can exceed the maximum depth of flow as computed using the equation shown in the bottom corner of Figure C0685.2.

(f) Design procedure. In designing level border irrigation systems, the designer needs to do one or more of the following:

(1) Determine the length of run that can be irrigated with a given stream size at a given efficiency level.

(2) Determine the stream size needed to irrigate a given length of run at a given efficiency level.

(3) Determine the maximum flow depth to be expected when using a given stream size and the length of run that can be irrigated with this stream at a given level of efficiency.

(4) Determine the allowable stream size and the related length of run for a given efficiency level.

(5) Before the above determinations can be made, the designer must have knowledge of the intake characteristics of the soil and must select a coefficient of roughness value (n) appropriate for the crop to be irrigated. He also must select the design depth of application (F_n).

(g) Design charts. To simplify the design procedure and eliminate the necessity of using time consuming trial and error procedures, design charts have been developed in Chapter 4, NEH, Section 15. Each chart is for a single intake family, a single coefficient of roughness "n" and a single net depth of application (F_n). The Level Border Irrigation Design Charts are versatile. Almost any known or assumed value(s) can be used to obtain other design values. A more complete explanation of the use of the level border design charts is given on page 4-16 of Chapter 4.

(1) Any two of the following design values must be known or assumed and then the others can be determined by the use of the charts.

- Length of run.
- Q_u (irrigation stream per foot of border width).
- Depth of flow.
- Efficiency desired.
- Time of application.

(2) Gross irrigation application is determined by dividing the net moisture to be replaced (F_n) by the application efficiency.

(3) Example - Use of level border design charts.

(i) Given:
Soil: Nunn Loam (Arapahoe CO.)
Length of run: 1000'
Soil intake family = 0.3
Crop to be irrigated is alfalfa

(ii) Determine:

(a) Moisture to Replace (F_n)
(b) Efficiency (E)
(c) Roughness coefficient (n)
(d) Stream Size (Q_u)
(e) Time of application (T_a)
(f) Depth of flow (d_1)
(g) Border ridge height
(h) Gross Depth of application (F_g)

(iii) Solution:

(a) From Section C0681.20 in Part 681 - Soils, for Nunn loam find: Moisture to replace (F_n) = 3.4" at 50% moisture and 4 foot root depth. <u>Use 3.0".</u>

(b) From Table C0685.62 find recommended application efficiency at 80%.

(c) From Table C0685.61 for the alfalfa crop; the "n" is 0.15.

(d) From Figure C0685.3 (same as pg. 4B-6, Chapter 4, NEH - Sec. 15) Q_u = 0.030 cfs/ft of width and

(e) T_a = 170 minutes

(f) Depth of Flow:
From Table C0685.60, intake opportunity time (T_n) is 392 minutes. From Table C0685.2 find T_t/T_n at 0.58 for an efficiency of 80%. Then Advance Time (T_t) in minutes is 0.58(392) = 227 min. From Fig. C0685.2 find d_1 = 0.37 ft. Add 0.15 for freeboard. Ridge height is then 0.37 + 0.15 = 0.52 feet. Gross irrigation is 3.0/0.8(12) = 0.31 ft. This is less than 0.52 feet; so use 0.52 feet for ridge height.

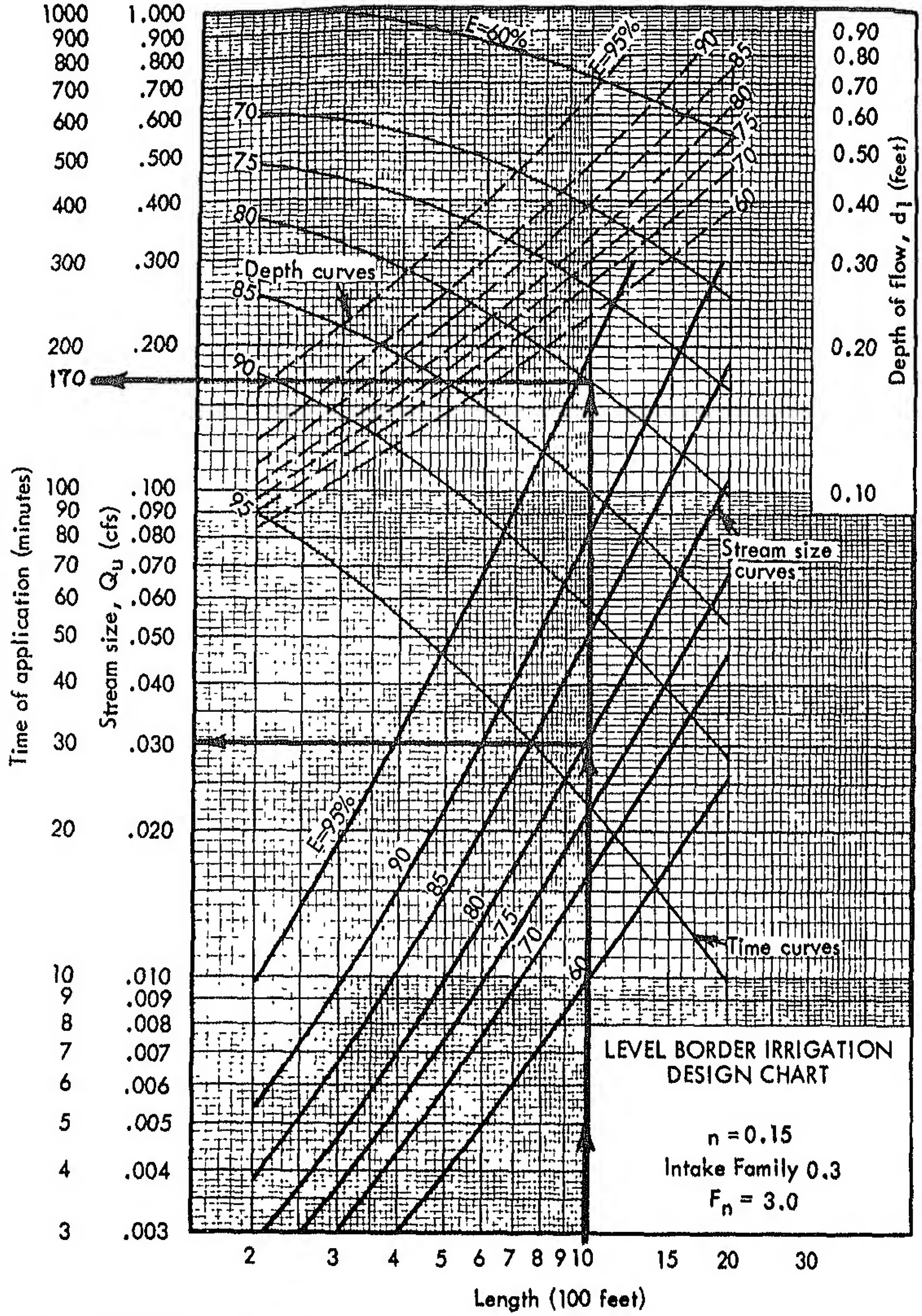


Figure C0685.3 Sample Level Border Irrigation chart.

C0685.11(g)(iii)

(g) Gross Application (F_g) is

$$F_g = \frac{720\ Q_u\ T_a}{L} = \frac{(0.030)(170)(720)}{1000} = 3.67 \text{in.}$$

(h) An evaluation of the system should be made after installation to be sure the basic assumptions of intake characteristics and "n" value are correct.

C0685.12 Graded borders.

(a) General design requirement. Graded border irrigation is a balanced advance-recesssion method of water application. The border strips have some slope in the direction of irrigation, and the ends usually are open. Each strip is irrigated by turning in a stream of water at the upper end. The stream should be such that the desired volume of water is applied to the strip in a time equal to, or slightly less than, that needed for the soil to absorb the net amount required. When the desired volume of water has been delivered onto the strip, the stream is turned off. The water temporarily stored on the ground surface then moves on down the strip and completes the irrigation. Uniform and efficient application of water with the graded border method is dependent upon the use of irrigation streams of the proper size. Too large a stream will result in inadequate irrigation at the upper end of the strip or excessive surface runoff at the lower end. If the stream is too small, the lower end will be inadequately irrigated or the upper end will have excessive deep percolation; or both conditions may occur. Legumes, grasses, and small grains commonly are irrigated by this method.

(1) This method of irrigation is best suited to soils that have a moderately low to a moderately high intake rate (0.5 through 3.0 intake families). It is not used on high intake rate coarse sandy soils because of the stringent limitations on the design.

(2) Graded borders are more suited to slopes of less than 0.5 percent. If rainfall erosion is not a hazard, and the soil intake is not too low, the method can be used on steeper slopes. <u>This method should be limited to slopes no steeper than six percent.</u>

(b) Advantages and limitations. Border strips can be designed for irrigation grades that will minimize land leveling costs and depth of cut where this item is critical in relatively shallow soils. Field application efficiency is excellent when strips are designed and installed properly. Labor requirements are low; but considerable skill in irrigating is needed.

(c) Design procedure. In designing graded border irrigation layouts, the designer needs to do one or both of the following:

(1) Determine the stream size needed to irrigate a given length of run.

(2) Determine the length of run that can be irrigated with a given stream size.

(i) Before this determination can be made, certain design values must be known or must be assumed. The following design values are dependent upon the soil, crop and/or topography in the design area.

Design Values	Depending Upon
Intake Family (I_f)	Soil texture
Irrigation Slope (S_0)	Topography (can be altered)
Roughness Coefficient (n)	Crop
Depth of application (F_n)	Soil and Crop
Application Efficiency (E)	Slope, Soil, and Crop
Non-Erosive Stream Size (Q_u)	Slope and Crop

(d) Field efficiency. Except in instances where a design limitation is approached, the selection of a design efficiency level is not critical. Usually it is possible for the irrigator to make sufficient stream-size adjustments to make the design layout operate satisfactorily. In all methods of irrigation, efficiency levels are affected more by the irrigator's management practices than by any other factor. Higher efficiencies can be expected on gentle slopes than on steep slopes. Table C0685.63 shows the efficiencies commonly assumed for designing graded border irrigation.

C0685.12(e)(1)

(e) Border strip length.

(1) Long border strips are easier to farm than shorter lengths because long strips require fewer turns for farm equipment. However, factors other than flow hydraulics may determine the maximum lengths of run in specific fields. Field boundaries, barriers, such as stream channels and drainage ditches, may often limit strip lengths. Border strips should not be laid out across two or more soil types which have significantly different intake characteristics and/or available water capacities. Also, border strips should not extend across major slope changes.

(2) Even under the most favorable conditions, the time required to patrol very long runs, and the problems in determining stream size adjustments usually make long runs impractical. Lengths of run in excess of one-quarter mile are not recommended.

(f) Design limitation.

(1) The stream size used in graded border irrigation must be non-erosive. Table C0685.64 gives the maximum non-erosive stream sizes for both non-sod and sod forming crops on various slopes.

(i) For non-sod forming crops such as alfalfa and small grain:

$$Q_{u\ max} = 0.0019\ (S_0)^{-0.75}$$

(ii) For well established, dense sod crops:

$$Q_{u\ max} = 0.0038\ (S_0)^{-0.75}$$

(2) The irrigation stream must be large enough so that the water spreads over the entire border strip. A larger stream is needed on rough strips than on smoothly graded strips. The minimum value of Q_u/L for various "n" values and slopes is given in Table C0685.65.

(3) The maximum slope for graded borders is limited by minimum depth of flow or by a minimum border length of 100 feet. Table C0685.66 shows these maximum slopes. Although very steep irrigation slopes are theoretically possible, erosion may be high for slopes over six percent.

(4) The theoretical maximum length of run for graded border irrigation is computed by the formula:

$$L = 7.2\ Q_u\ (T_n - T_L)\ (E/F_n)$$

Where:

Q_u - Stream size (cfs) per foot of width
T_n - Time of net application in minutes
T_L - Recession lag time in minutes
E - Efficiency in percent
F_n - Net application in inches.

(5) On some soils with low intake rates and gentle slopes, the theoretical maximum length of run can be several thousand feet. In practice, border lengths in excess of one-quarter mile seldom should be designed.

(g) Maximum Depth of Flow

(1) The flow depth at the head end of the border strip must not exceed some practical depth related to construction and maintenance of the ridges. Therefore, a flow depth in excess of 6 inches is inadvisable. Depths of 8 to 10 inches should seldom be considered. Table C0685.65, Minimum Value of Q_u/L to Assure Complete Border Width Coverage, can be used to determine Q_u values. This table was developed from computation of water surface profiles using "n" values of 0.04, 0.15, and 0.25.

(h) Minimum Depth of Flow.

(1) The irrigation stream must be large enough so that the water spreads over the entire border strip. A larger stream is needed on rough strips than is required on well graded smooth strips. The irrigation stream per foot of strip width should be no less than is computed by:

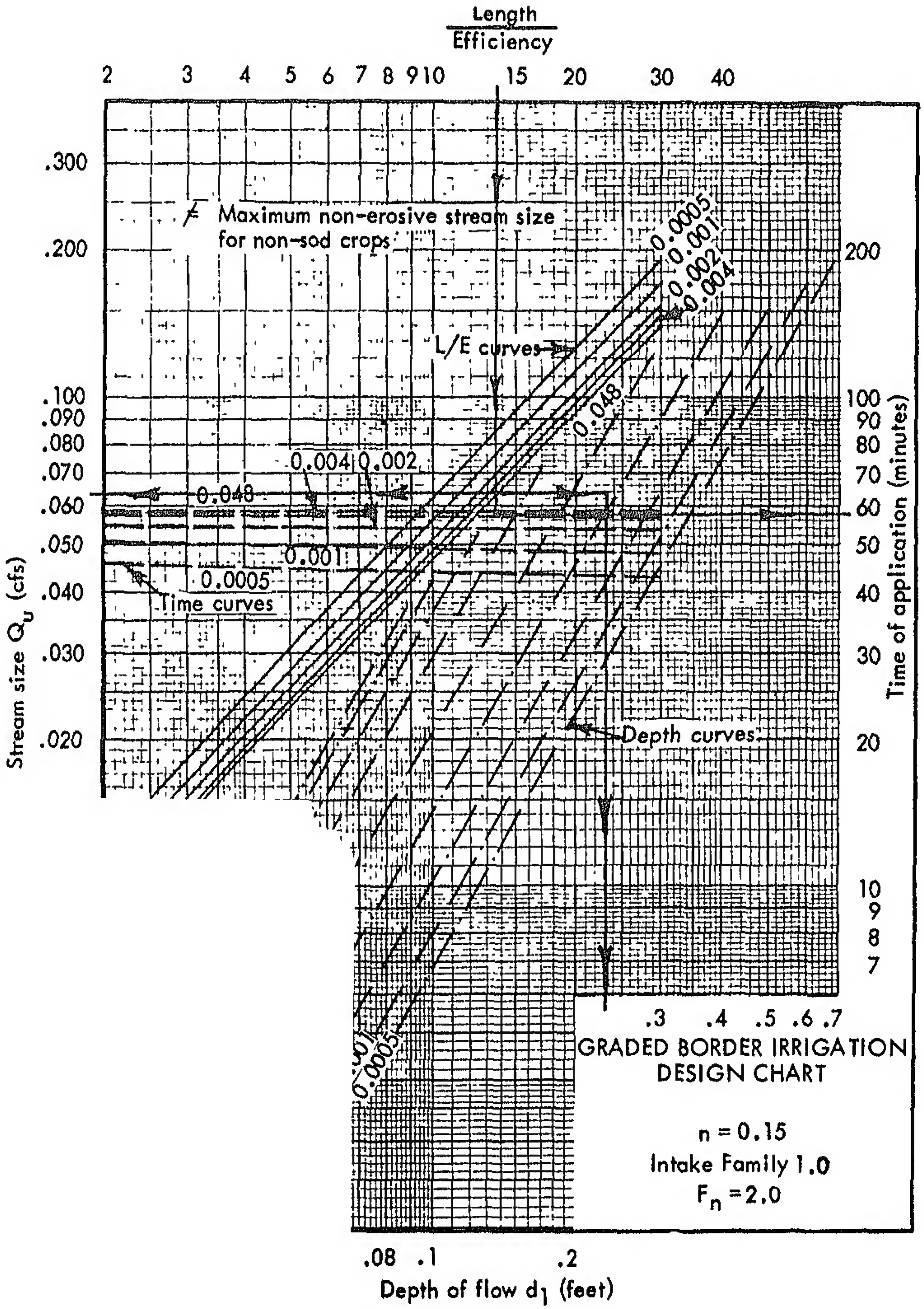
$$Q_u = \frac{0.000064}{n}\ L\ (S_0)^{0.5}$$

Table C0685.65 shows the minimum value of Q_u/L for various slopes and "n" values.

(i) Design charts.

(1) Chapter 4 of NEH, Section 15, contains design charts for the solution of the graded border irrigation design equations. Each chart is for a single intake family I_f, roughness coefficient "n", and a single net depth of application F_n.

C0685.12(i)(1)



Graded Border Irrigation chart.

(2) The design charts for Graded Border Designs are not as versatile as those for Level Border Design. The charts are arranged so that for any selected efficiency almost any other known or assumed value can be used as a starting point, however, <u>the charts should not be used to determine efficiency values</u>. A more detailed explanation of the use of the Graded Border Irrigation Design Charts is given on page 4-36 of NEH 15, Chapter 4.

(3) Example 1 - Use of graded border design charts.

(i) Given:
Soil - Julesburg Sandy Loam
Length of run - L = 800 feet
Irrigation slope - S = .005 ft/ft
Available water Q = 2.0 cfs
Crop is small grain, broadcast planted

(ii) Determine:
(a) Moisture to replace (F_n)
(b) Intake family I_f
(c) Roughness coefficient (n)
(d) Efficiency (E)
(e) Unit stream (Q_u)
(f) Border strip width (W)
(g) Depth of flow at head of run (d_1)
(h) Time of application (T_a)

Note: Use Chapter 4, Section 15 NEH for reference.

(iii) Solution:

(a) In Section C0681.20 find Julesburg Sandy Loam. Soil holds 4.46" @ 3 feet and 5.54" @ 4 feet of depth. Small grain has a rooting depth of 3 feet. At 50 percent depletion replace 2.2": therefore use:

F_n = 2.0" (closest chart value) and,

(b) Intake family I_f = 1.0

(c) Roughness coefficient
n = 0.15 (Table C0685.61)

(d) Efficiency
E = 60% (Table C0685.63)

(e) Unit stream Q_u

$L/E = 800/60 = 13.3$

$Q_u = 0.063$ From NEH 15, Chapter 4, page 4E-11, shown here as figure C0685.4

(f) Width (W)

$$W = \frac{Q}{Q_u} = \frac{2.0}{0.063} = 32 \text{ feet}$$

(g) Depth of Flow (d_l)

$d_l = 0.23$ ft (Figure C0685.4)

(h) Time of Application (T_a)

$T_a = 60$ minutes (Figure C0685.4)

(i) Check max. and min. Q_u and max. W.

Max Width W = 60 feet (Table C0685.1) ok

Max $Q_u = 0.101$ (Table C0685.64) > 0.063 ok

Min $\frac{Q_u}{L} = 0.00003017$ (Table C0685.65)

Min $Q_u = .00003017(800) = 0.024 < 0.063$ ok

$d_l = 0.23 + \text{freeboard} = 0.38$ feet.

Part 685 - Irrigation Methods and Design Criteria

SUBPART C - FURROW AND CORRUGATION IRRIGATION

C0685.20 General design considerations.

(a) There are four kinds of furrow systems: Level furrows, graded straight furrow, graded contour furrows and corrugations. Furrow irrigation is suitable for most irrigable soils if the depth and surface topography permit the needed land leveling to be done economically. They can be adapted for nearly all irrigated crops except those requiring ponded water.

(b) Furrow irrigation has many advantages on suitable sites. Some of these are:

(1) Irrigation streams can be large or small as needed by adjusting the number of furrows irrigated by one flow rate.

(2) The water distribution systems do not normally require high water pressures.

(3) Water is not applied directly on the plants, thus eliminating scalding of the foliage and loss of insecticides.

(4) Excellent field surface drainage is obtained.

(5) Alternate-row irrigation allows greater use of rainfall.

(c) Furrow irrigation also has certain limitations. Some of these are:

(1) Salt from either the soil or water supply may concentrate in the ridges and depress crop yields.

(2) The lateral spread of water in some soils is not adequate to provide full irrigation.

(3) Differences in intake opportunity time along the furrow length makes uniform application depth difficult.

(4) Soil-erosion potential limits their use to flat slopes.

(5) Labor requirements may be high because of the need to regulate furrow streams.

(6) Leaching of salts from furrow ridges is difficult or impossible.

C0685.20(d)

(d) A well planned furrow irrigation system must provide assurances that water can be applied uniformly and efficiently. Soil intake rates vary from one irrigation to the next throughout a season. Cultural practices, compaction, soil tilth, cropping patterns, and other factors have a large influence on the rate that water infiltrates into the soil. To obtain efficient irrigation, the rate and time of application should be in accordance with the soil intake rate that is present during a specific irrigation. This judgment on the part of the irrigator is difficult to accomplish, but is essential for successful furrow irrigation.

(e) Figure C0685.5 shows intake families and advance coefficients. Some assumptions or approximations must be made in developing design equations and tables.

C0685.21 Design and evaluation.

(a) Chapter 5, Furrow Irrigation, Section 15, of the SCS National Engineering Handbook contains formulas and charts for solving furrow irrigation design problems. Separate design equations and procedures are used for three types of furrows or corrugations; Graded furrows, Cutback-inflow furrows, and level furrows.

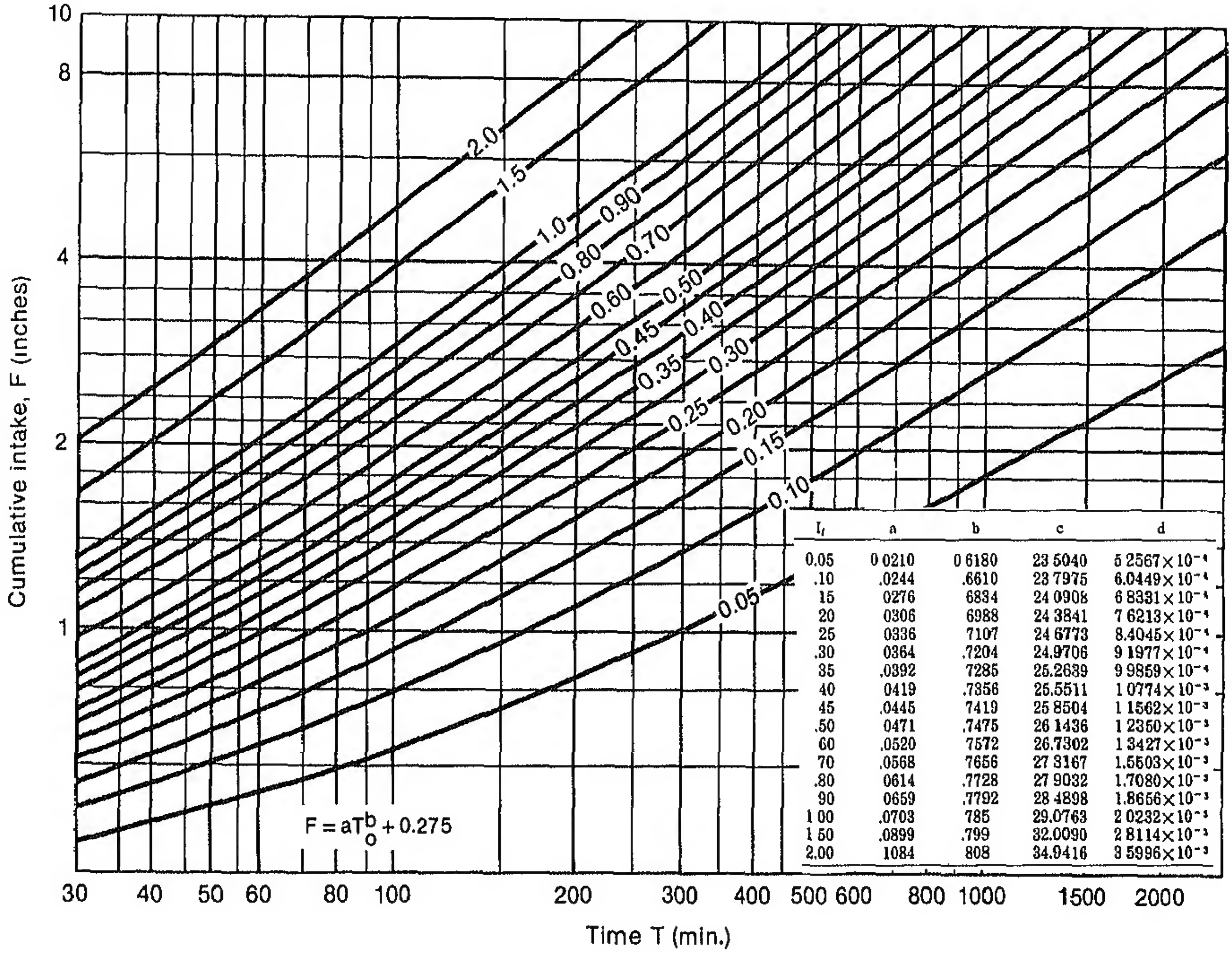
(b) The charts are based on the following assumptions:

(1) The rate of advance diminishes as the size of the stream is reduced while moving downstream, thereby, reducing the velocity and/or rate of advance. Therefore, the time of advance is a function of flow rate, slope, length, and furrow intake family (I_f).

$$T_t = \frac{L}{c}(e)^x$$

where:

T_t = Advance time in minutes
L = Length of furrow in feet
c = 23.2110 + 5.8653 I_f (See figure C0685.5)
d = 0.00044685 + 0.0015764 I_f (See figure C0685.5)
Q = Furrow stream size in gpm
S = Furrow slope in ft. per foot
e = 2.71828 (a mathematical constant)
x = $(dL/Q(S)^{0.5})$



I_f	a	b	c	d
0.05	0.0210	0.6180	23.5040	5.2567×10^{-4}
.10	.0244	.6610	23.7975	6.0449×10^{-4}
15	0276	6834	24.0908	6.8331×10^{-4}
20	0306	6988	24.3841	7.6213×10^{-4}
25	0336	7107	24.6773	8.4045×10^{-4}
.30	0364	.7204	24.9706	9.1977×10^{-4}
35	.0392	7285	25.2639	9.9859×10^{-4}
40	0419	.7356	25.5511	1.0774×10^{-3}
45	.0445	7419	25.8504	1.1562×10^{-3}
.50	0471	.7475	26.1436	1.2350×10^{-3}
60	.0520	7572	26.7302	1.3427×10^{-3}
70	.0568	7656	27.3167	1.5503×10^{-3}
.80	0614	.7728	27.9032	1.7080×10^{-3}
90	0659	.7792	28.4898	1.8656×10^{-3}
1.00	.0703	785	29.0763	2.0232×10^{-3}
1.50	.0899	.799	32.0090	2.8114×10^{-3}
2.00	1084	808	34.9416	3.5996×10^{-3}

Figure C0685.5 Intake Families for Furrow Design

(2) The furrow wetted perimeter (P) is a function of flow rate, slope, and Mannings "n", plus a constant. The constant is adjusted to account for the horizontal and vertical movement of water along the wetted perimeter.

$$P = 0.2686 \left[\frac{Q(n)}{S^{0.5}} \right]^{0.4247} + 0.7462$$

The value of 'P' determined by this equation cannot exceed the furrow spacing (W).

C0685.21(b)(3)

(3) The application depth (F_n) is computed at the lower end of the furrow, solving the cumulative intake equation for a time equal to the inflow time minus the advance time to the end of the furrow. The depth is converted to an equivalent depth by multiplying by the wetted perimeter plus a constant and dividing by the furrow spacing (P/W). This ratio (P/W) cannot be greater than 1.

$$F_n = [a(T_i - T_t)^b + 0.275] \, P/W$$

Where:
- F_n = Application depth in inches
- a = Coefficient (see figure C0685.5)
- T_i = Inflow time in minutes
- T_t = Travel time to end of furrow in minutes
- b = Coefficient (see figure C0685.5)

(4) The average opportunity time for intake is determined by subtracting the average advance time from the inflow time. The average advance time is obtained by intergrating the advance equation.

$$T_o = T_i - \left[\frac{1}{cL\,(d/QS^{1/2})^2}\left[\left(\frac{dL}{QS^{1/2}} - 1\right) e^{(dL/QS^{1/2})} + 1\right]\right]$$

(5) The gross application (F_g) is determined as the product of inflow time, divided by the furrow length, and multiplied by a unit conversion.

$$F_g = \frac{1.6041 \, Q \, T_i}{WL}$$

Where:
- F_g = Gross Application in inches
- Q = Furrow inflow in gpm
- T_i = Inflow time in minutes
- W = Furrow spacing in feet
- L = Furrow length in feet

(6) Runoff (RO) is the remainder of gross application less the average intake.

$$RO = (F_g - F_{ave.})$$

Where:

$$F_{ave.} = (a\ T_o{}^b + .275)\ P/W$$

(7) Deep percolation (DP) occurs:

(i) When application depth at the distal end of the furrow is less than the design application: The deep percolation volume which exceeds the design application (F_n) is computed and expressed as an equivalent depth over the entire furrow length.

$$DP = [P/W\ (\ a\ (T_{ox})^b + 0.275) - F_n]\ X/L$$

where: T_{ox} = Same as T_o with X replacing L
X = Distance down the furrow where application depth equals F_a.
X is determined through trial and error from

$$(X/c)(e)^X = \left[\frac{T_i - F_n(W/P) - 0.275}{a}\right]^{1/b}$$

(ii) When application at the distal end of the furrow equals or exceeds the design application depth: Deep percolation is the gross application less the sum of runoff (RO) and the design application depth.

$$DP = F_g - (RO + F_d)$$

(8) Efficiency, in percent:

(i) When application at the end of the furrow equals or exceeds the design application, efficiency is the ratio of the design application to the gross application times 100.

$$AE = \frac{F_n}{F_g}\ (100)$$

(ii) When design application is applied at a point that is less than the furrow length L, the efficiency becomes:

$$AE = \frac{100\ (F_{ox} - DP)}{F_g}$$

where:
F_{ox} = the average application over the distance X.

C0685.21(c)

(c) This procedure is best suited for analyzing existing systems, otherwise, the solution becomes a series of trial and error computations.

(d) Example 1

(1) Given: Intake Family I_f = 0.5
Length = 900 feet
Field width = 660 feet
Q = 2.5 cfs
Slope = 0.003
Sets = 3 per field
n = 0.04
Design Application = 3.0 inches
Spacing = 30" (2.5 ft.)

(2) Find: Application time (T_i)
Gross application (F_g)
Runoff (RO)
Deep percolation (DP)
Efficiency (AE)

(3) Solution: Number of Furrows per set is:

$$\text{Furrows} = \frac{660}{3} \times \frac{12}{30} = 88$$

$$Q_i \text{ per furrow} = \frac{2.5(448.8)}{88} = 12.75 \text{ gpm}$$

From figure C0685.5 find intake and advance coefficients for an intake family of 0.5:

$$a = .0471 \quad b = .7475 \quad c = 26.1436 \quad d = 1.2350 \times 10^{-3}$$

Advance time:

$$T_t = (900/26.1436)(2.7183)^x$$

$$\text{01235})/(12.75)(0.003)^{.5} = 1.5916$$

$$36)(2.7183)^{1.5916}$$

s

$$75)(0.04)/(0.003)^{.5})^{0.4247} + 0.7462$$

Net Opportunity Time:

$$T_n = \left[\frac{(3.0)(2.50/1.44) - 0.275}{0.0471}\right]^{1/0.7475}$$

= <u>504 minutes</u>

Application time T_i:

$T_i = T_t + T_n = 169 + 504 =$ <u>673 minutes</u>

Gross application F_g

$$F_g = \frac{1.6041Q\ T_i}{WL} = \frac{1.6041(12.75)(673)}{2.5\ (900)}$$

= <u>6.12 inches</u>

Average Opportunity time:

$$T_{(0-L)} = T_i - \left[\frac{1}{cL\left(\frac{d}{QS^{1/2}}\right)^2}\left(\frac{dL}{QS^{1/2}} - 1\right)e^{(dL/QS^{1/2})} + 1\right]$$

$(dL/QS^{.5}) = 1.5916 = x$ from computation of advance time on p. C0685-24, therefore,

$$T_{(0-L)} = 673 - \frac{(1.5916 - 1)(2.7183)^{1.5916} + 1}{(26.1436)(900)(1.5916/900)^2}$$

$= 673 - 53$

= <u>620 minutes</u>

Average intake:

$F_{(0-L)} = ((0.0471)(620)^{0.7475} + 0.275)1.44/2.5$

= <u>3.48 inches</u>

Deep percolation:

$D = F_{(0-L)} - F_n = 3.48 - 3.00 =$ <u>0.48 inches</u>

Surface Runoff:

$RO = F_g - F_{(0-L)} = 6.12 - 3.48 =$ <u>2.64 inches</u>

C0685.21(d)(3)

Efficiency:

$$AE = 100 \frac{F_n}{F_g} = \frac{100(3.0)}{6.12} = 49\%$$

(4) Summary:
$Q = 12.75$ gpm
$T_i = 673$ minutes (11.21 hours)
$F_g = 6.12$ inches

RO = 2.64 inches
DP = 0.48 inches
AE = 49%

C0685.22 Cablegation System and Design

(a) Cablegation is a form of gated-pipe system. The gates or outlets are near the top side and are always left open or partly open (see figure C0685.6). The pipe is laid on a precise grade and a plug moves at a controlled speed slowly through the pipe causing water to flow in sequence to furrows or bordered strips in the field.

(b) Various design considerations are needed for cablegation systems. Some of these are:

(1) Consideration must be given to handling excess water at the inlet structure as the plug starts down the pipeline. This may be handled by:

(i) An overflow system at the inlet structure.
(ii) Starting the plug at its outlet flow length down the pipeline.
(iii) Regulating the flow to the inlet until full flow condition is reached.
(vi) Installing a bypass line in the cablegation line. (See figure C0685.7)

(2) The size of the pipe outlets must be adequate to discharge the maximum flow to be expected for present and future crops.

(3) Provisions are needed to handle debris and sediment that may be encountered in the delivery water. Excess debris will plug the outlets and sediment deposited in the bottom of the pipeline will hang up the plug. Adequate screening and periodic flushing of the line will generally handle these problems.

(4) A uniform pipe grade is needed. Pad work may place the pipe sufficiently above the field grade to create an erosive condition. Provisions must be made to safely deliver the water to field grade. A split grade may be placed on the mainline but special attention will be needed for the reel design to assure a uniform advance rate and water volume across the field.

(5) A selection of the cable release mechanism. Four are presently available:

(i) An electric control motor, if electricity is present.

(ii) A battery (12V/dc) operated release mechanism. Security is often needed to prevent theft of the battery. Provisions are needed to recharge the battery or alternate with another battery. Commercial mechanisms now allow for approximately 30 days of battery use before recharging.

(iii) Hydraulic cylinder controllers (Figure C0685.8).

(iv) An octagon water control brake, as shown on Figure C0685.8.

(6) A selection of the type of outlet. Some means is needed to regulate and control the discharge from the outlets. Several commercial outlets on the market will function adequately. The selected outlet should:

(i) Not protrude beyond 1/4 inch into the pipeline.

(ii) Be able to be locked or fixed into position. Some slides will move when the plug passes and are not adequate.

(7) The selection of plug material and design dimensions.

(8) Selection of the cable material. Some rope products allow too much stretch, allowing for variation in stream flow characteristics.

(c) The cablegation system is advantageous in that it is readily adaptable to several existing systems. It has a water saving ability by providing cutback irrigation and is labor saving in its automated concept.

(d) Publication ARS-21, "Cablegation Systems for Irrigation" of the Agricultural Research Service contains Description, Design, Installation, and Performance data for cablegation systems.

C0685.22(e)(1)

(e) Design formulas and charts are based on the following assumptions:

(1) The grade of the supply pipe equals the neutral or friction slope. The Hazen-Williams formula then becomes:

$$H_r = 473 \ (Q/C)^{1.85} / (D)^{4.87}$$

where:
- H_r = Head loss in feet per 100 ft. of pipe
- Q = Water flow rate in cu. ft./sec.
- D = Pipe inside diameter in ft.
- C = Hazen-Williams roughness coefficient; for aluminum pipe C = 130, for plastic pipe C = 150.

(2) Dimensionless equations for the head, H, at the outlet nearest the plug and distance, X, were developed for ranges of pipe sizes from 4 to 15 inches in diameter, slopes from 0.001 to 0.05, C values from 110 to 150, flow ratios Q/Q_c from 0.5 to 0.95 and outlet diameters from 1/4 to 4 inches.

$$H/D = 13.8(C/150)^{0.76} \ (S)^{1.03} \ (Q/Q_c)^{0.46} \ (FD/d^2)^{0.56}$$

where:
- H = Head on the traveling plug (in)
- D = Supply pipe inside diameter (in)
- S = Slope (ft/ft)
- F = Outlet spacing (in)
- d = Outlet diameter (in)
- Q = Total pipe flow (gpm)
- Q_c = Full pipe flow capacity (gpm)

and:

$$X/D = 9.8 \ (C/150)^{0.44} (Q/Q_c)^{1.1} (FD/d^2)^{0.67}$$

where:
- X = Distance along pipe through which outlets are flowing

(3) The maximum outlet stream size q_m in gpm can be determined by using a standard outlet equation

$$q_m = 3.69 \ d^2 \ (H)^{0.5}$$

with d and H in inches.

(4) The outlet diameter can then be computed by combining equations

$$d = 0.00217(qm)^{0.69} \left[(C/150)^{.76} (D)^{1.56} (F)^{0.56} (S)^{1.03} (Q/Q_c)^{.46} \right]^{-0.347}$$

(5) The plug speed is a function of inflow Q, gross application and furrow length.

$$P = 3600\ Q/L\ F_g$$

Where P is in feet per hour

(f) Design example:

(1) Given: Intake Family (I_f) = 0.3
Length of field (L) = 1300 ft
Q = 550 gpm (1.225 cfs)
Pipe Slope = 0.008 ft/ft
Outlet size (d) = 1.26 inches
Outlet spacing (F) = 30 inches
Furrow slope (S) = 0.005
Gross application (F_g) = 2" (0.1667 ft)
Assume that pipe is 8" PVC Lo Head and Hazen-Williams C is 150.

(2) Solution:

(i) Head Loss (H_r) in supply pipe

$$H_r = 473\ (1.225/150)^{1.85} / (0.667)^{4.87}$$

$$= 0.466 \text{ ft}/100 \text{ ft}$$

(ii) Compute Maximum Flow (Q_c) for Pipe slope of 0.008 or 0.8ft/100ft.

$$0.8 = 473\ (Q_c/150)^{1.85} / (0.667)^{4.87}$$

$$Q_c = 1.64 \text{ cfs}$$

Then the ratio of Q/Q_c = 1.225/1.64 = 0.75

(iii) Compute head (H) on traveling plug

$$H = 13.8(8)(1)^{0.76}(.008)^{1.03}(0.75)^{0.46} \frac{[30(8)]^{0.56}}{[(1.26)^2]^{0.56}}$$

$$= \underline{11.1 \text{ inches}}$$

C0685.22(f)(2)(iv)

(iv) Compute distance X through which outlets are flowing:

$$X = 8(9.8)(1)^{0.44}(0.75)^{1.1}\frac{[30(8)]^{0.67}}{(1.26)^{1.34}}$$

$$= \frac{1648.6 \text{ in}}{12 \text{ in/ft}}$$

$$= \underline{137.4 \text{ feet}}$$

(v) Compute maximum outlet stream (q_m) size:

$$q_m = 3.69\ (1.26)^2\ (11.1)^{1/2}$$

$$= \underline{19.5 \text{ gpm}}$$

Average outlet stream size is:

$$\frac{19.5 + 0}{2} = 9.75$$

(vi) Compute plug speed (P):

$$P = 3600\ Q/LF_g = 3600(1.225)/1300(0.1667)$$

$$= \underline{20.35 \text{ feet/hr}}$$

(vii) Inflow time (T_i) then is time for plug to travel distance X:

$$T_i = 137.4/20.35 = \underline{6.75 \text{ hrs}}$$

(viii) Opportunity time (T_o) is:

From Figure C0685.5 and $I_f = 0.3$
$a = 0.0364$ $b = 0.7204$
$c = 24.9706$ $d = 9.1977 \times 10^{-4}$

$$T_o = T_i - T_t = T_i - (e)^x(L/c)$$

$$= (6.75)(60) - (e)^x\ (1300/24.9706)$$

Where:
$e = 2.7183$
$x = dL/Q(S)^{0.5}$
$= (0.00091977)(1300)/(9.75)(0.005)^{0.5}$
$= 1.73$

$T_o = (6.75)(60) - (2.7183)^{1.73}(1300/24.9706)$

$= \underline{110 \text{ minutes}}$

(ix) Net application (F_n) is:

$F_n = aT^b + 0.275$

$= .0364(110)^{.7204} + 0.275$

$= \underline{1.35 \text{ inches}}$

(x) Runoff (RO) is:

RO = 2.00 inches - 1.35 inches = <u>0.65 inches</u>

(3) Summary
Plug speed = 20.35 ft/hr
Outlet stream q_m = 19.5 gpm
Net application = 1.35 inches
Runoff = 0.65 inches

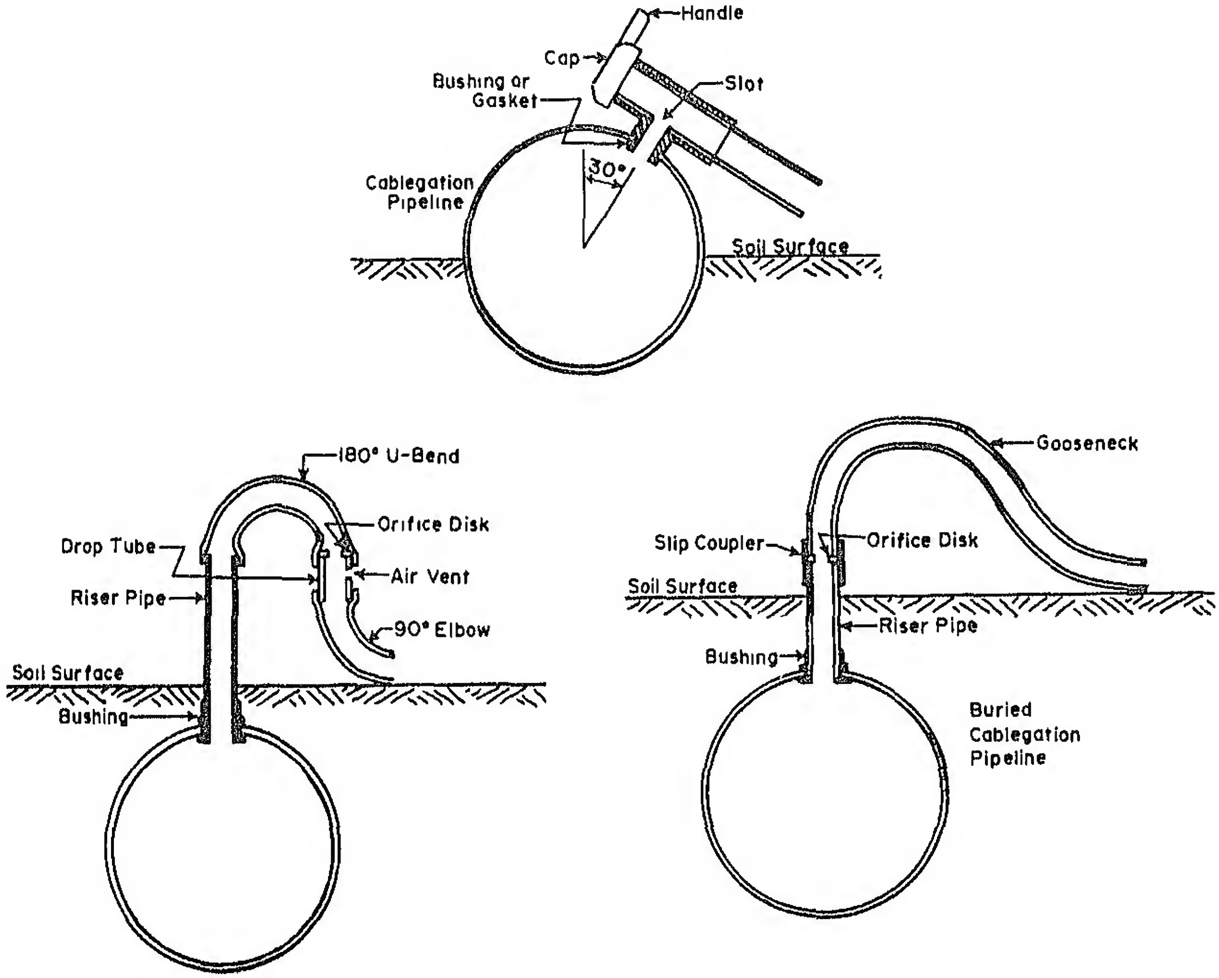


Figure C0685.6 - Typical Cablegation Outlets

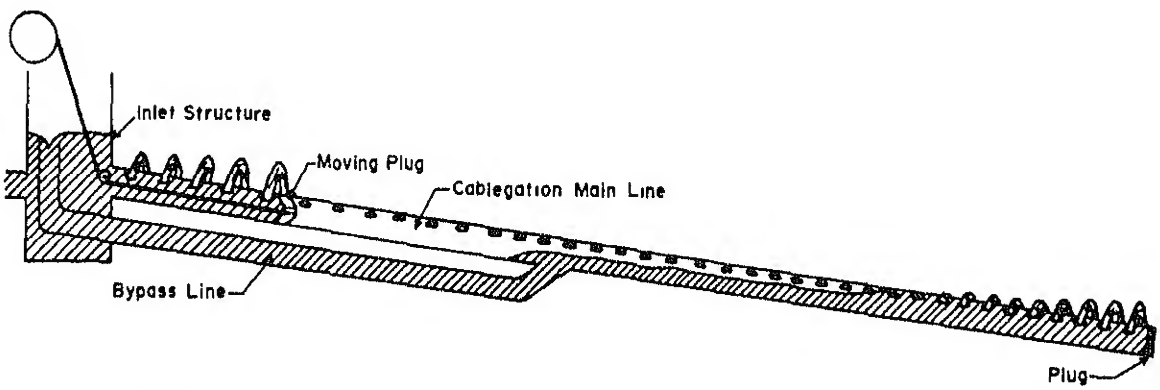
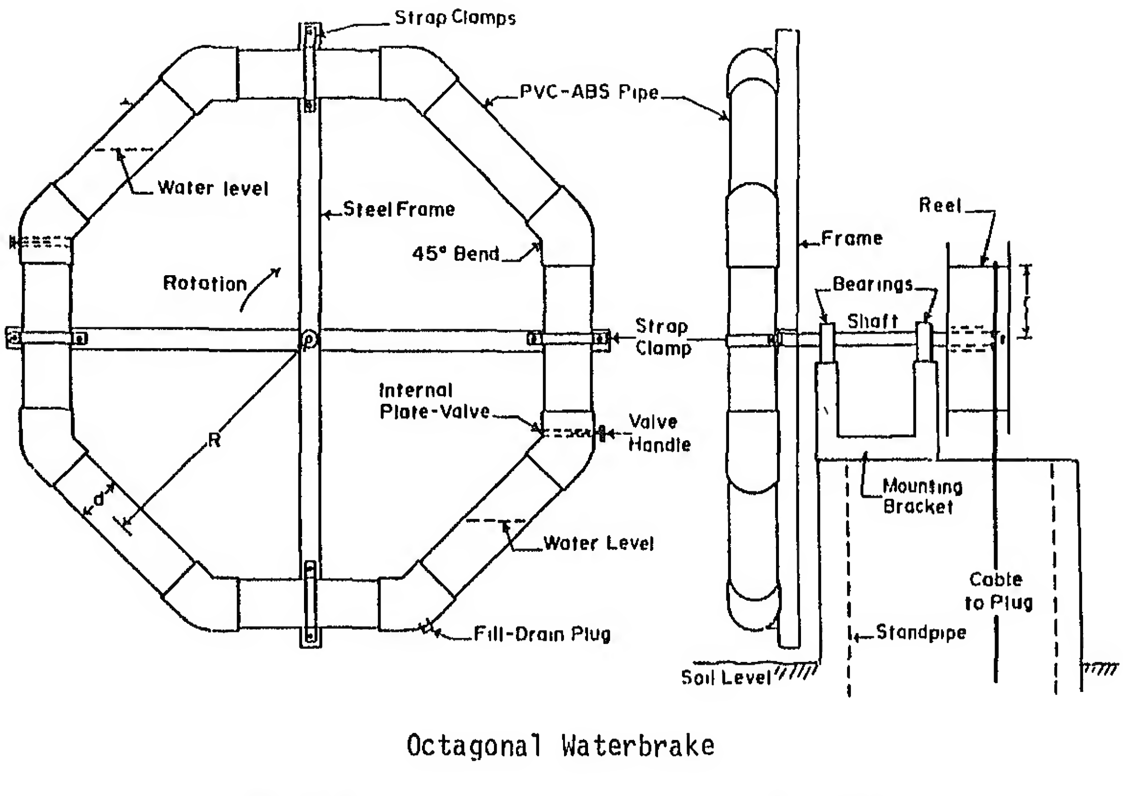
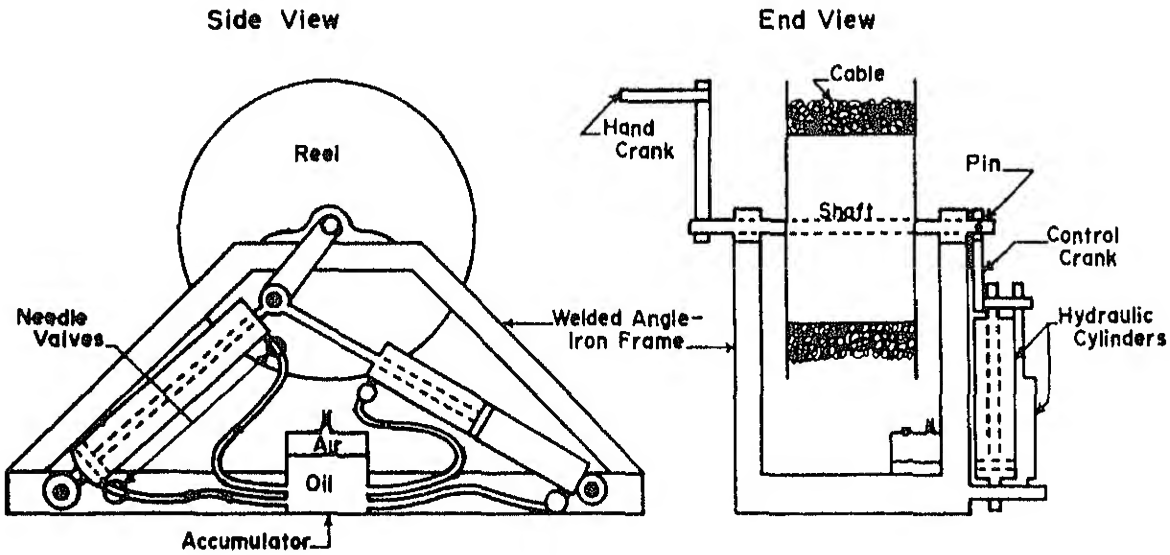


Figure C0685.7 - Cablegation Bypass Line



Octagonal Waterbrake



Hydraulic Cylinder

Figure C0685.8 Cablegation Reel Controllers

C0685.23 Kinematic wave model

(a) The Kinematic Wave Model, based on work by Dr. Wynn R. Walker at Utah State University, shows less deep percolation and more runoff than the procedures contained in NEH Section 15, Chapter 5. However, the sum of deep percolation and runoff, by both methods, is very nearly the same. The Kinematic Wave Model gives net application within ± 0.5 inches from procedures in Chapter 5.

(b) The Kinematic Wave Model is perhaps the most accurate method available for evaluating furrow irrigation. However, accuracy of the model is commensurate with the intake family number used as imput. Specific intake family numbers have not been derived for all irrigated soils in Colorado. Also, it is known that intake rates change during the season due to cultivation practices, irrigation events, and other factors. Therefore, judgement is needed when assigning the intake family number for a soil.

(c) Figures C0685.9 and C0685.10 reflect evaluations based on 2-inch and 3-inch net application using intake family numbers of 0.3, 0.5, 0.7, 1.0, and 1.5; furrow length of 600, 900, 1300, and 1800 feet; and furrow slope of 0.25, 0.5, 0.75, 1.0, and 1.5 percent. Factors held constant for these evaluations are: a corn crop with 30 inch row spacing and mannings roughness coefficient of 0.04. One hour is the time increment used for optimizing the time of set.

(d) Figures C0685.9 and C0685.10 show optimum furrow flow rate and time of set for furrow length and intake family. Furrow slope has negligible effect on flow rate and time of set.

(e) Conclusions drawn from these evaluations are:

Item	Percent of Net App.
Runoff	33
Deep Perc.	33
App. Eff.	55-60

›w irrigation (Section C0685.24) improves the
›iency of furrow irrigation by reducing runoff
›ion.

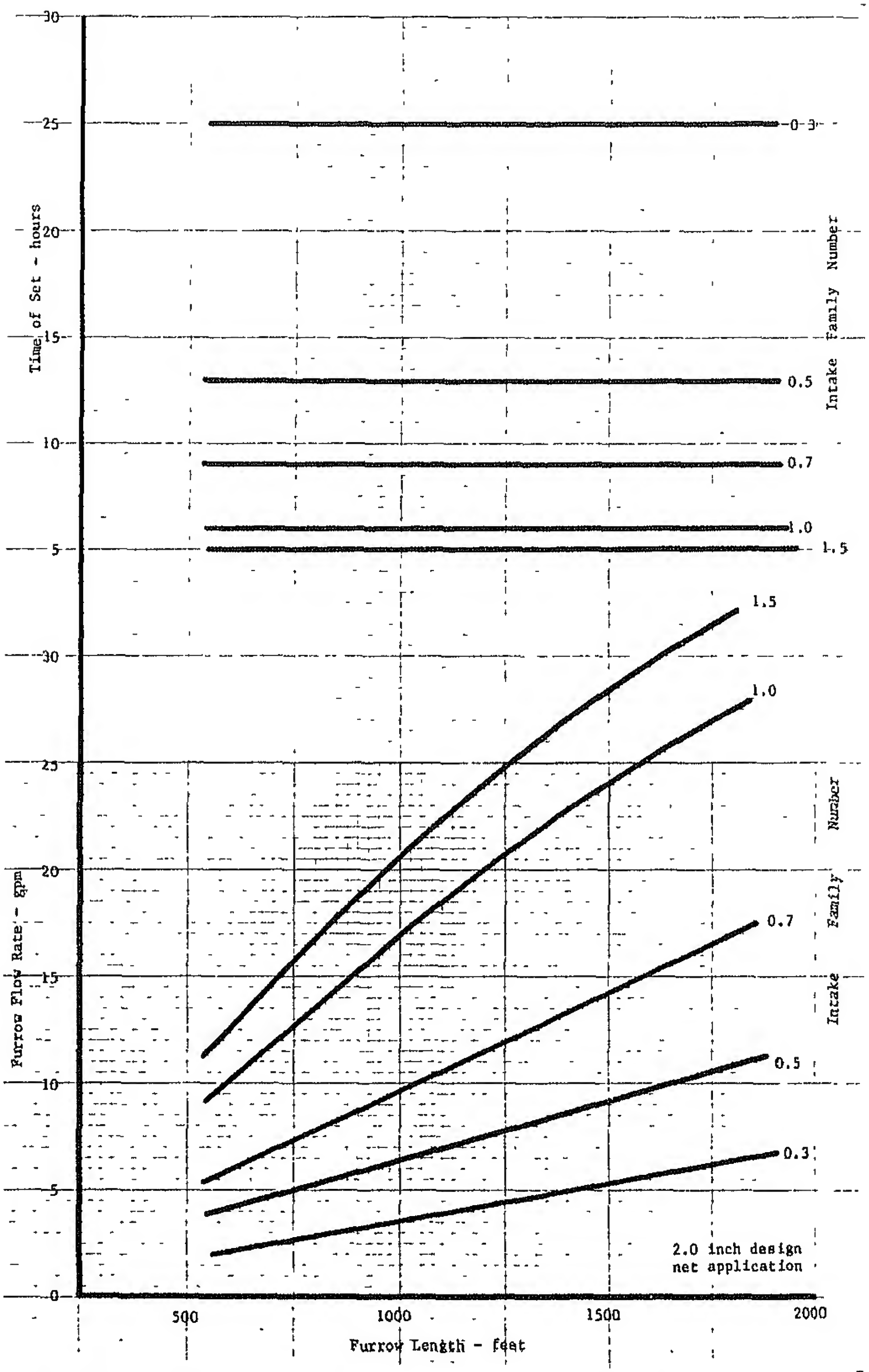


Figure C0685.9 Flow Rate and Time of Set for Optimum Furrow Irrigation based on the Kinematic Wave Model

C0685.23 Kinematic wave model

(a) The Kinematic Wave Model, based on work by Dr. Wynn R. Walker at Utah State University, shows less deep percolation and more runoff than the procedures contained in NEH Section 15, Chapter 5. However, the sum of deep percolation and runoff, by both methods, is very nearly the same. The Kinematic Wave Model gives net application within $\pm$ 0.5 inches from procedures in Chapter 5.

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(e) Conclusions drawn from these evaluations are:

Item	Percent of Net App.
Runoff	33
Deep Perc.	33
App. Eff.	55-60

(f) Surge flow irrigation (Section C0685.24) improves the application efficiency of furrow irrigation by reducing runoff and deep percolation.

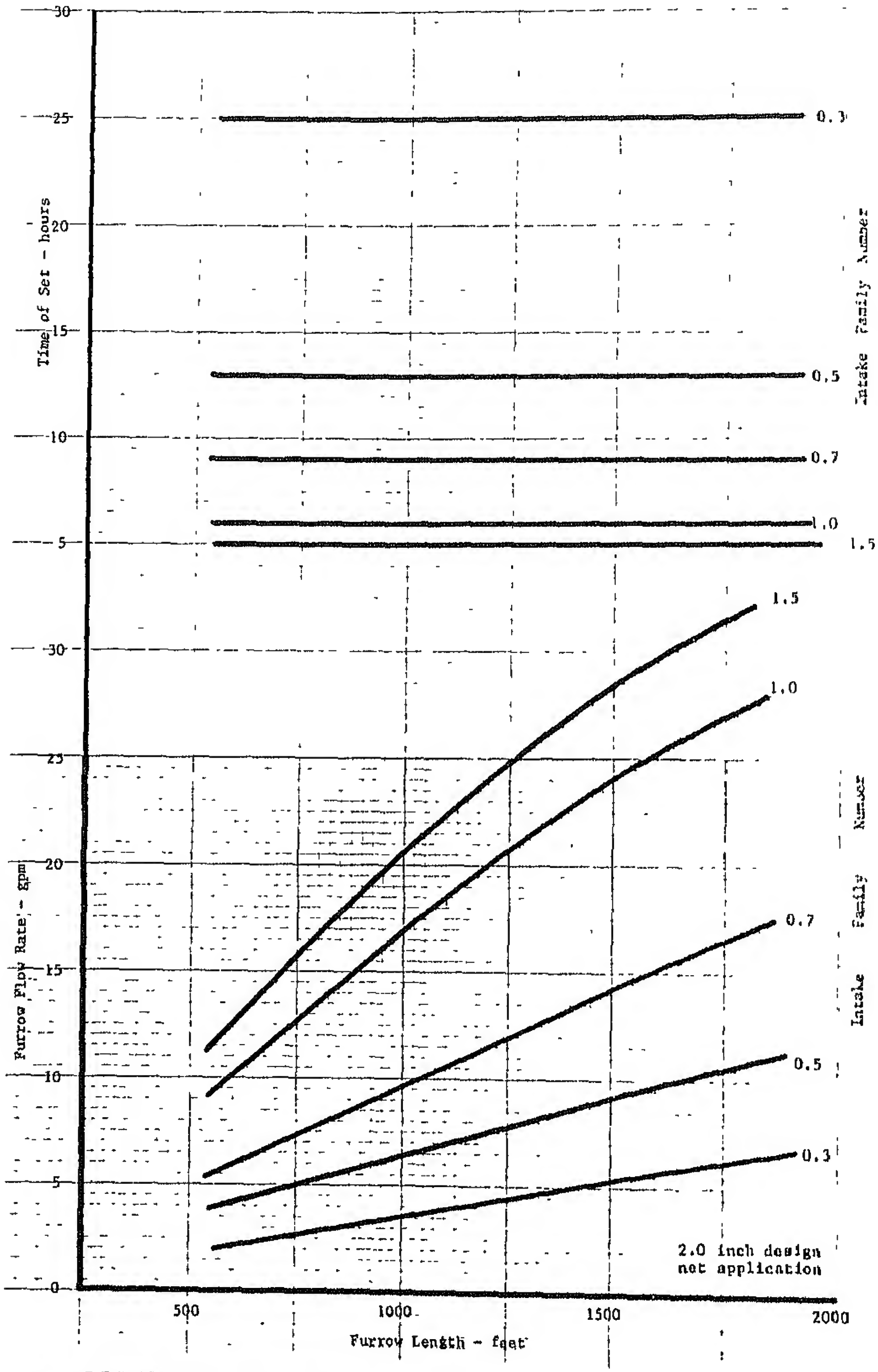


Figure C0685.9 Flow Rate and Time of Set for Optimum Furrow Irrigation based on the Kinematic Wave Model

C0685.23

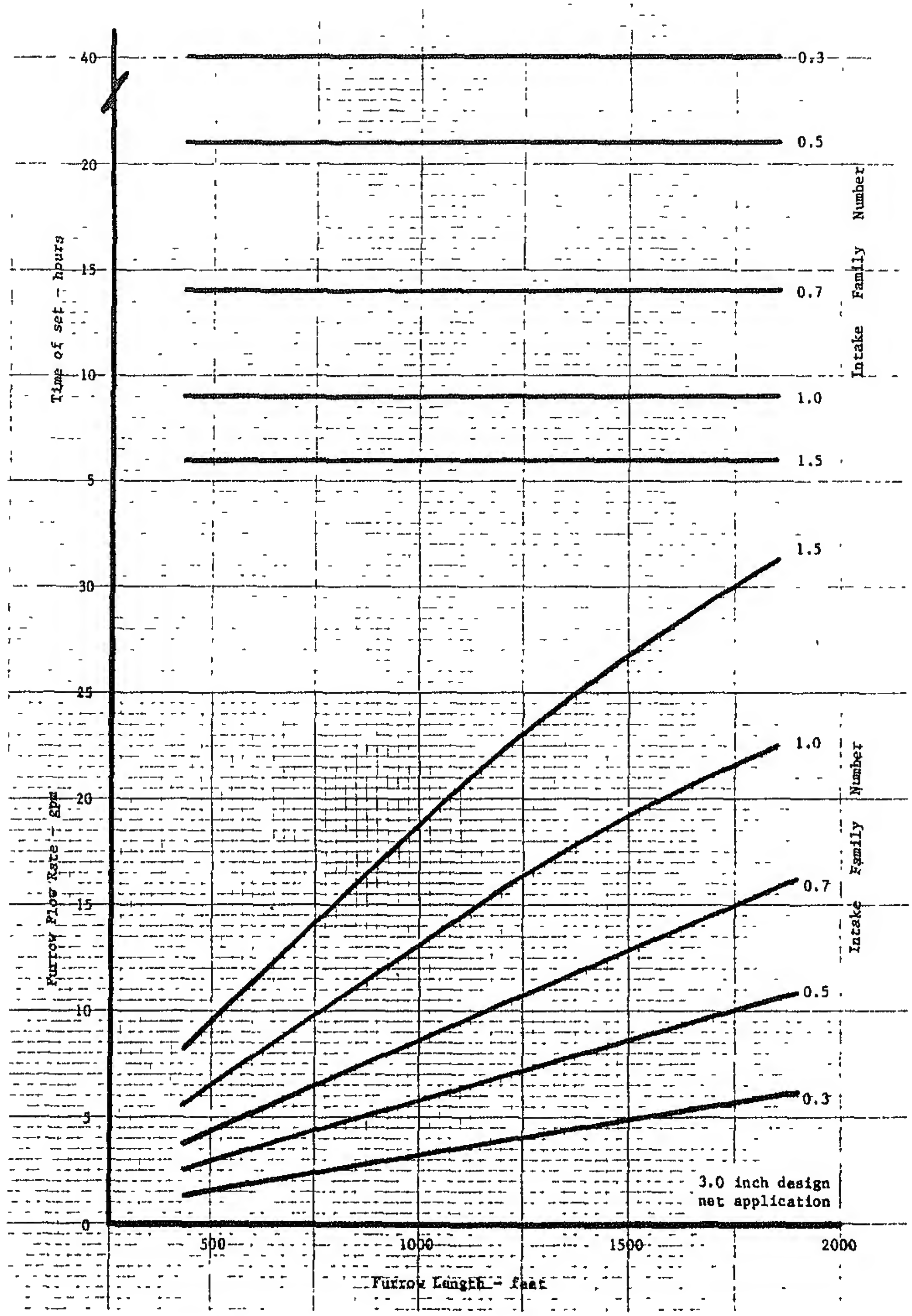


Figure C0685.10 Flow Rate and Time of Set for Optimum Furrow Irrigation based on the Kinematic Wave Model

C0685.24 Surge flow irrigation

(a) Definition: Surge flow irrigation typically alternates the application of water for equal periods of time between two sets of furrows using a gated pipe system. One set of furrows is on each side of a control valve. Solar charged programmable electronic units are available to monitor each on-time and to operate the control valve. On-time is defined as that time interval when water is flowing in one set of furrows, contrasted with off-time when water is not flowing in that set of furrows. One on-time and one off-time constitute one cycle. Off-time must permit surface water to percolate into the soil. On-time should be sufficient to get water through the furrow in three to six cycles depending on length of furrow.

(b) Objectives: Achieving water conservation is the primary purpose for using surge flow irrigation. The irrigator needs to apply adequate and uniform irrigations to assure crop quality and quantity. Both requirements will be met by establishing the number and duration of on-times appropriate for the soil, length of run, and other field conditions.

(c) Precision: Inaccuracies inherent in surge flow irrigation include:

(1) Wetted furrow length. Water advances farther and faster in wheel rows than in non-wheel rows. Also, not all wheel rows or all non-wheel rows will be wetted to the same length with each on-time.

(2) Furrow flow rate. Flow rate may not be uniform in all furrows. In fact, the flow rate in wheel rows may intentionally be cut back to achieve uniform advance and minimize runoff.

Because of these and other inaccuracies, evaluation of surge flow irrigation using Figure C0685.12 should not be expected to achieve application precision more than plus or minus one-half inch per irrigation.

(d) Evaluation of surge flow irrigation: The evaluation of surge flow irrigation should provide the means to assess the adequacy and uniformity of subsequent irrigations using tools available to the irrigator in the absence of other technical assistance.

C0685.24(e)

(e) Procedure and Activity

(1) Mark the field length in increments of 100 feet. Pacing these increments is sufficiently accurate.

(2) Determine soil moisture depletion to establish the net amount of water to be applied by irrigation. Depletion may be represented by the summation of crop "ET" since the previous irrigation verified by field probing.

(3) Estimate the time of set needed to replenish the soil moisture deficit. Time of set is related to net application, area to be irrigated, and flow rate.

(4) Determine average flow rate per furrow by measuring the flow into several furrows. With negligible leakage from the system, average furrow flow rate can be calculated as total stream flow divided by number of gates flowing.

(5) Determine average advance distance during each on-time by sighting across the set at or between 100 feet increments of field length. Distance to the closest 50 feet is sufficient.

(6) Determine average net application using Fig. C0685.12 and Table C0685.3 with average furrow flow and average advance distance.

(7) Estimate the potential depth of moisture penetration by dividing average net application by the inches per inch of moisture holding capacity of the soil.

(8) Probe the field to ascertain actual and adequate depth of moisture penetration and to establish post-irrigation moisture content of the soil.

(9) Develop recommendations for adjusting on-time, number of furrows, or other aspects of the irrigation process to improve irrigation adequacy and uniformity.

(f) Formulation of Recommendations

(1) The irrigator must balance the number of cycles required to apply the needed amount of water with the on-time for each cycle. Each first condition on-time should be such that approximately uniform increments of dry furrow are wetted each time, or that water reaches the end of the dry furrow in a whole number of uniform time increments. After initial wetting of the full length of furrow, the second condition on-time should only permit water to advance nearly the full length of wetted furrow.

(2) Once appropriate on-times have been established, the number of cycles can be determined from Fig. C0685.12. Cumulatively adding on-time until water reaches the end of the furrow gives the average application during initial wetting. This usually is less than the needed depth of application. The second condition on-time gives the depth applied with each soaking application. The amount of soaking water to be applied is the difference between needed depth and initially applied depth. The number of soaking cycles is determined by dividing the needed amount of soaking water by the amount of soaking water applied per on-time.

(3) Establishing an appropriate number and duration of on-times is the end product of this method of evaluation.

(g) Data Reduction

(1) Fig. C0685.12, Table C0685.3, and Fig. C0685.11 enable quick evaluation of surge irrigation. Required data includes on-time, average furrow flow rate, average length of wetted furrow during each on-time, and average advance time through the full length of wetted furrow.

(2) To use Fig. C0685.12 enter the bottom left side with the cumulative sum of on-time and find the intersection with average furrow flow rate. Then read horizontally across to find the intersection with observed length of wetted furrow at the end of the last on-time. At this point read the average depth of application for a 30-inch row spacing, provided that no runoff occurred. For row spacing different from 30 inches, enter Table C0685.3 with depth of application read from the chart, move horizontally across to the column corresponding to the actual row spacing, and read depth of application for that row spacing. Once water reaches the end of the furrow enter Fig. C0685.12 with advance time through the full length of wetted furrow. A sample evaluation illustrates the use of Fig. C0685.12 and Table C0685.3.

(3) Fig. C0685.12, based on volume balance, is independent of soil intake. The furrow flow rate and soil intake rate influence length of wetted furrow during each on-time. Until runoff occurs the water applied replenishes an equal volume of soil moisture deficit. Deep percolation occurs when the applied volume exceeds soil moisture deficit.

(4) Application uniformity is inversely proportional to length of newly wetted furrow during each on-time. The shorter the newly wetted length, the more uniform is the opportunity time and, therefore, the more uniform is the application.

(h) Field Check

(1) An adequate irrigation will have been achieved when the design net application has been uniformly applied. Soil moisture deficit before irrigation establishes the design application. The deficit can be estimated by the summation of daily crop ET and precipitation since the previous irrigation. Actual deficits should be verified periodically by field probing or other testing rather than relying solely on ET data.

(2) Adequate application uniformity will have been achieved when depth of moisture penetration closely corresponds with root zone depth. Depth of penetration reasonably can be determined by probing the soil following irrigation.

WORKSHEET FOR EVALUATING SURGE IRRIGATION

Farm Example
Technician J. Smith
Soil Name Ravola
Irrigation Event Number 3
Average Furrow Flow Rate 20 gpm.

Field 3
Date Jun 21, 1988
Crop Corn
Design Net App. 2.75 in.
Furrow Length 1300 ft.
Row Spacing 2.5 ft.

(1) ON-TIME (No.)	(2) ON-TIME 5/ (min.)	(3) Sum of On-Time 1/ (min.)	(4) Average Advance (ft.)	(5) Average Net App. 2/ (in.)	(6) Average Net App. 6/ (in.)	(7) Sum of Net App. 4/ (in.)
1	40	40	500	1.0	1.0	--
2	45	85	880	1.25	1.25	--
3	50	135	1100	1.55	1.55	--
4	55	190*	1300	1.9	1.9	-- 1.9
5	55	230	1300	0.5	0.5	-- 2.4
6	55	-- 270	1300	0.5	0.5	2.9
7		--				
8		--				
9		--				
10		--				
11		--				
12		--				
TOTALS		--	--	--		

Total Irrig. Time $= \frac{2\ (\text{Col.}2)}{60\ \text{min/hr.}} = \frac{2(270)}{60} = $ 9.0 hrs.

Advance time through furrow 55 min. 3/

1/ Cummulative sum until water reaches end of average furrows.
2/ Read from chart using on-time from Col.3 and distance from Col.4.
3/ Measured advance time for water to reach end of previously wet furrow.
4/ Cummulative sum of average net application when water reached end of furrow and subsequent applications.
5/ Begin with on-time for water to advance 1/3 to 1/2 through the dry furrow. Then change to advance time for water to reach end of wetted furrow.
6/ Read from table for row spacing different from 1.0 ft. using data from Col.5.

Figure C0685.11 Surge Irrigation data Sheet

C0685.24 (h)(2)

Figure C0685.12 Surge Flow Depth of Application

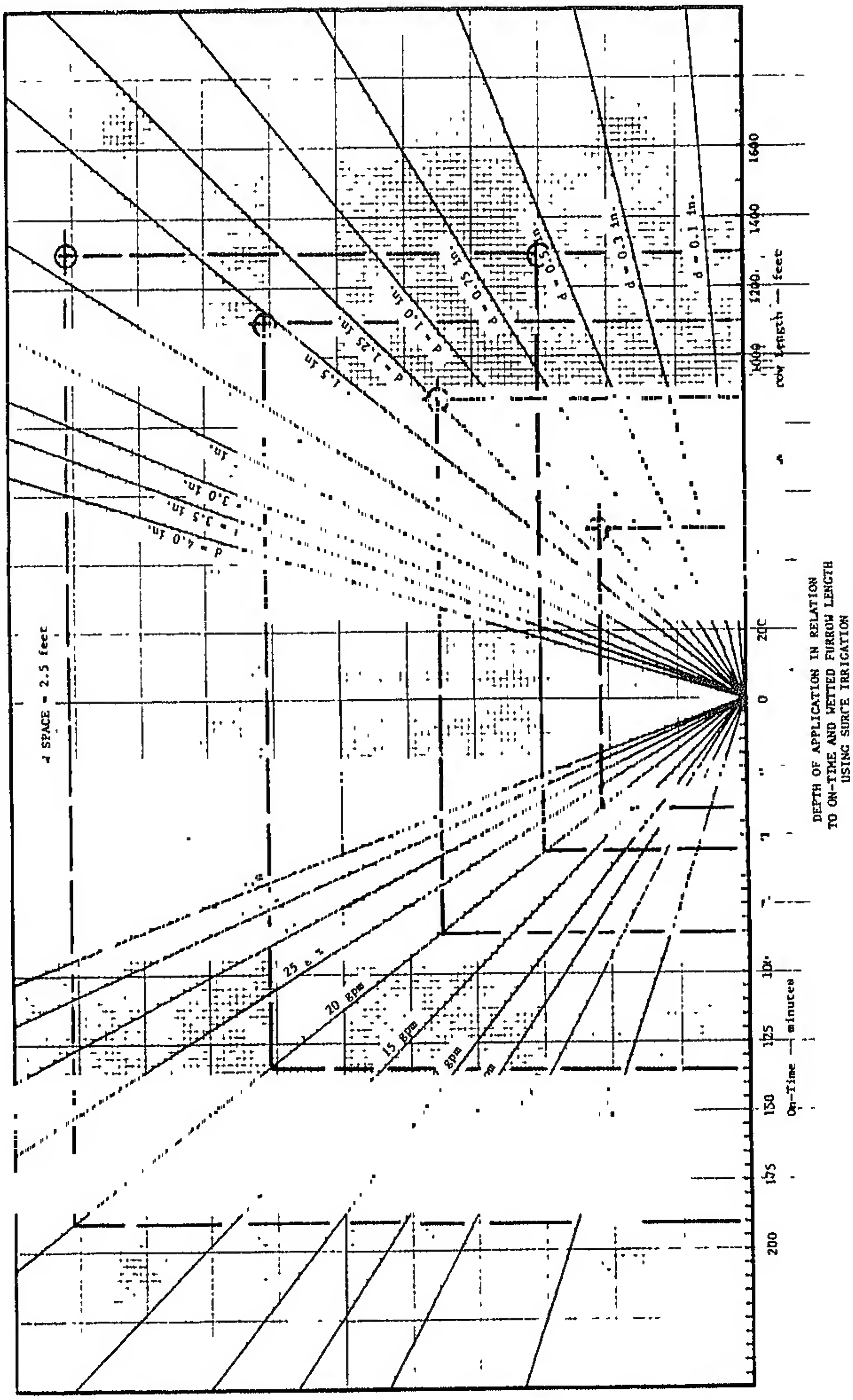


Table C0685.3 Depth of Application for Various Row Spacings

DEPTH OF APPLICATION FOR DIFFERENT ROW SPACING
(inches)

Applied Depth for 30 - in. Space (in.)	Row Spacing - feet													
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0
8.00	20.00	13.33	10.00	8.00	6.67	5.71	5.00	4.44	4.00	3.33	2.86	2.50	2.22	2.00
7.60	19.00	12.67	9.50	7.60	6.33	5.43	4.75	4.22	3.80	3.17	2.71	2.38	2.11	1.90
7.20	18.00	12.00	9.00	7.20	6.00	5.14	4.50	4.00	3.60	3.00	2.57	2.25	2.00	1.80
6.80	17.00	11.33	8.50	6.80	5.67	4.86	4.25	3.78	3.40	2.83	2.43	2.13	1.89	1.70
6.40	16.00	10.67	8.00	6.40	5.33	4.57	4.00	3.56	3.20	2.67	2.29	2.00	1.78	1.60
6.00	15.00	10.00	7.50	6.00	5.00	4.29	3.75	3.33	3.00	2.50	2.14	1.88	1.67	1.50
5.60	14.00	9.33	7.00	5.60	4.67	4.00	3.50	3.11	2.80	2.33	2.00	1.75	1.56	1.40
5.20	13.00	8.67	6.50	5.20	4.33	3.71	3.25	2.89	2.60	2.17	1.86	1.63	1.44	1.30
4.80	12.00	8.00	6.00	4.80	4.00	3.43	3.00	2.67	2.40	2.00	1.71	1.50	1.33	1.20
4.40	11.00	7.33	5.50	4.40	3.67	3.14	2.75	2.44	2.20	1.83	1.57	1.38	1.22	1.10
4.00	10.00	6.67	5.00	4.00	3.33	2.86	2.50	2.22	2.00	1.67	1.43	1.25	1.11	1.00
3.80	9.50	6.33	4.75	3.80	3.17	2.71	2.38	2.11	1.90	1.58	1.36	1.19	1.06	0.95
3.60	9.00	6.00	4.50	3.60	3.00	2.57	2.25	2.00	1.80	1.50	1.29	1.13	1.00	0.90
3.40	8.50	5.67	4.25	3.40	2.83	2.43	2.13	1.89	1.70	1.42	1.21	1.06	0.94	0.85
3.20	8.00	5.33	4.00	3.20	2.67	2.29	2.00	1.78	1.60	1.33	1.14	1.00	0.89	0.80
3.00	7.50	5.00	3.75	3.00	2.50	2.14	1.88	1.67	1.50	1.25	1.07	0.94	0.83	0.75
2.80	7.00	4.67	3.50	2.80	2.33	2.00	1.75	1.56	1.40	1.17	1.00	0.88	0.78	0.70
2.60	6.50	4.33	3.25	2.60	2.17	1.86	1.63	1.44	1.30	1.08	0.93	0.81	0.72	0.65
2.40	6.00	4.00	3.00	2.40	2.00	1.71	1.50	1.33	1.20	1.00	0.86	0.75	0.67	0.60
2.20	5.50	3.67	2.75	2.20	1.83	1.57	1.38	1.22	1.10	0.92	0.79	0.69	0.61	0.55
2.00	5.00	3.33	2.50	2.00	1.67	1.43	1.25	1.11	1.00	0.83	0.71	0.63	0.56	0.50
1.80	4.50	3.00	2.25	1.80	1.50	1.29	1.13	1.00	0.90	0.75	0.64	0.56	0.50	0.45
1.60	4.00	2.67	2.00	1.60	1.33	1.14	1.00	0.89	0.80	0.67	0.57	0.50	0.44	0.40
1.40	3.50	2.33	1.75	1.40	1.17	1.00	0.88	0.78	0.70	0.58	0.50	0.44	0.39	0.35
1.20	3.00	2.00	1.50	1.20	1.00	0.86	0.75	0.67	0.60	0.50	0.43	0.38	0.33	0.30
1.00	2.50	1.67	1.25	1.00	0.83	0.71	0.63	0.56	0.50	0.42	0.36	0.31	0.28	0.25
0.80	2.00	1.33	1.00	0.80	0.67	0.57	0.50	0.44	0.40	0.33	0.29	0.25	0.22	0.20
0.60	1.50	1.00	0.75	0.60	0.50	0.43	0.38	0.33	0.30	0.25	0.21	0.19	0.17	0.15
0.40	1.00	0.67	0.50	0.40	0.33	0.29	0.25	0.22	0.20	0.17	0.14	0.13	0.11	0.10
0.20	0.50	0.33	0.25	0.20	0.17	0.14	0.13	0.11	0.10	0.08	0.07	0.06	0.06	0.05

CO685.24(h)(2)

Exhibit A - Worksheet for Evaluating Surge Irrigation

WORKSHEET FOR
EVALUATING
SURGE IRRIGATION

Farm ____________________ Field ____________________
Technician ____________________ Date ____________________
Soil Name ____________________ Crop ____________________
Irrigation Event Number ____________________ Design Net App. __________ in.
Average Furrow Flow Rate __________ gpm. Furrow Length __________ ft.
Row Spacing __________ ft.

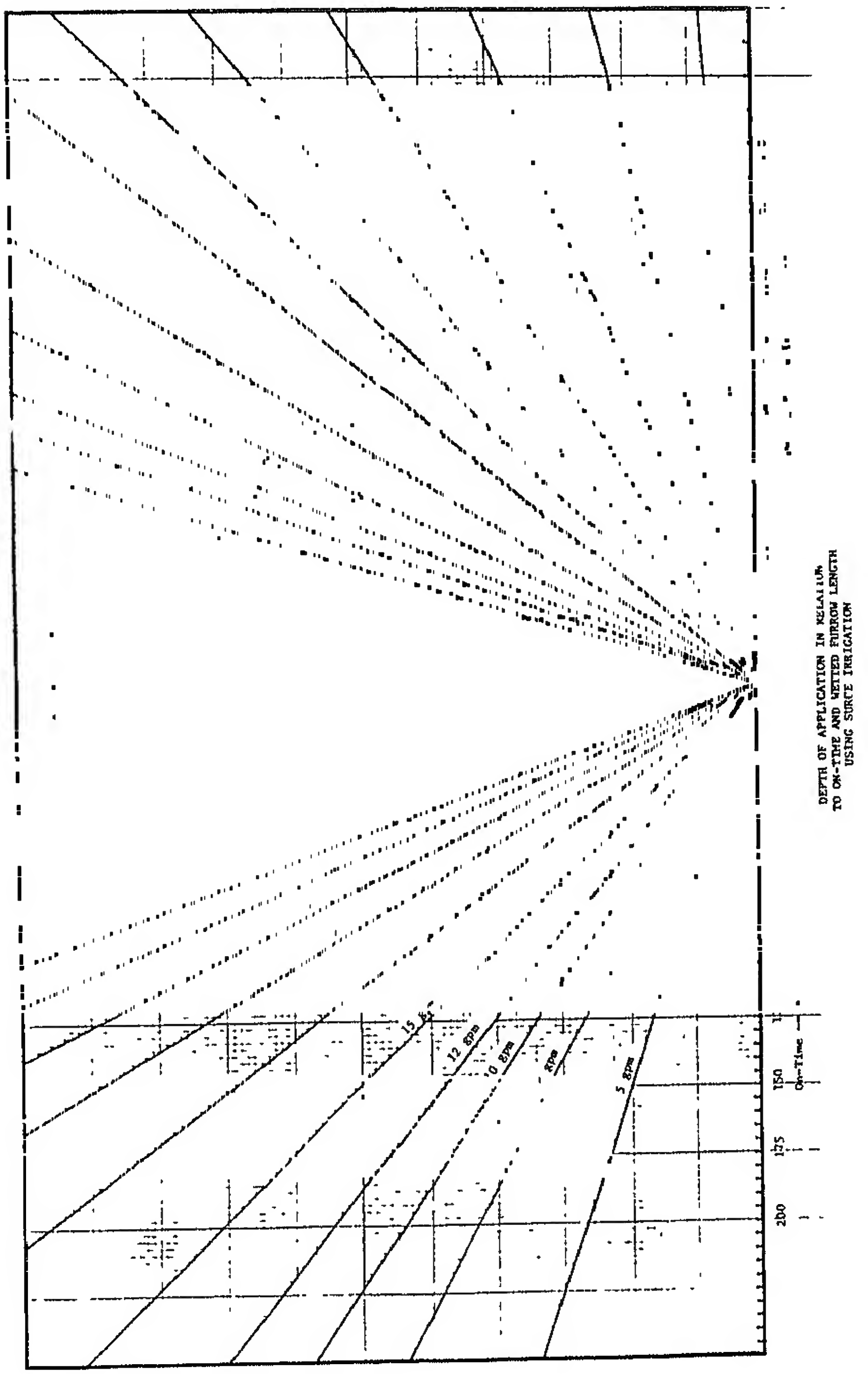
(1) ON-TIME (No.)	(2) ON-TIME 5/ (min.)	(3) Sum of On-Time 1/ (min.)	(4) Average Advance (ft.)	(5) Average Net App. 2/ (in.)	(6) Average Net App. 6/ (in.)	(7) Sum of Net App. 4/ (in.)
1						--
2						--
3						--
4						--
5						--
6		--				
7		--				
8		--				
9		--				
10		--				
11		--				
12		--				
TOTALS		--	--	--		

Total Irrig. Time = $\frac{2\ (\text{Col.2})}{60\ \text{min/hr.}} = \frac{2(\quad)}{60} =$ ____ hrs.

Advance time through furrow _____ min. 3/

1/ Cummulative sum until water reaches end of average furrows.
2/ Read from chart using on-time from Col.3 and distance from Col.4.
3/ Measured advance time for water to reach end of previously wet furrow.
4/ Cummulative sum of average net application when water reached end of furrow and subsequent applications.
5/ Begin with on-time for water to advance 1/3 to 1/2 through the dry furrow. Then change to advance time for water to reach end of wetted furrow.
6/ Read from table for row spacing different from 1.0 ft. using data from Col.5.

Exhibit B - Depth of Application Chart for Surge Irrigation



Part 685 - Irrigation Methods and Design Criteria

SUBPART D - SPRINKLER IRRIGATION

C0685.30 General design considerations.

(a) In sprinkler irrigation, the water is sprayed into the air and allowed to fall on the land surface in a uniform pattern at a rate approximately equal to or less than the intake rate of the soil. This method of water application is similar to rainfall.

(b) With a properly designed and operated system, efficiencies of 65 to 75 percent can be obtained. Sprinkler losses are due to evaporation from the sprinkler spray, from the soil surface or from moisture intercepted by the plant leaves during irrigation, and from non-uniform distribution due to the sprinkler pattern. Wind distorts the pattern and frequently this results in non-uniform application and reduces efficiencies below those given above. Table C0685.69 shows recommended Design Field Efficiencies for Sprinkler Systems.

(c) Intake rates under sprinkler irrigation do not conform to those for flood or furrow. Table C0685.70 has been prepared as a guide for maximum sprinkler application rates. A sprinkler system that applies water at a rate not to exceed that shown in the table will generally be satisfactory for use in applying irrigation water.

(d) Because equipment and techniques for the application of water by sprinklers is so varied, the following discussion is aimed at giving general guidelines for the selection of the type of equipment and design requirements.

C0685.31 Types of sprinklers.

(a) Sprinklers spray water onto the land through nozzles in the sprinkler heads. Nozzles are classified according to the pressure required for proper distribution of the water applied.

(1) Low pressure sprinklers operate at pressures of 5 to 15 pounds per square inch with a wetted diameter of 20 to 50 feet and a recommended minimum application rate of 0.40 inches per hour. These sprinklers are adapted to small acreages and where gravity pressure can be utilized. They should be used on soils with intake rates exceeding 0.50 inch per hour.

C0685.31(a)(2)

(2) Moderate pressure sprinklers are usually single nozzle, with an operating pressure of from 15 to 30 psi, a wetted diameter of 60 to 80 feet, and a minimum application rate of 0.20 inches per hour. Moderate pressure sprinklers are adapted primarily to undertree sprinkling in orchards.

(3) Intermediate pressure sprinklers are single or dual nozzle, with operating pressures of 30 to 60 psi; a wetted diameter of 75 to 125 feet, and a minimum application rate of 0.25 inches per hour. This type of sprinkler is adapted to a wide variety of soils and crops.

(4) High pressure sprinklers can be either single or dual nozzle type operating at pressures from 50 to 100 psi and providing a wetted diameter of 110 to 230 feet with a minimum application rate of 0.50 inches per hour. They are primarily adapted to truck crops, field crops, and pastures in areas where distortion of the pattern from wind is not excessive. They provide fast coverage with limited equipment.

(5) Hydraulic or giant sprinklers have a large nozzle with smaller supplemental nozzles to fill in pattern gaps. They operate at pressures of 80 to 120 psi and cover a wetted diameter of 200 to 400 feet with a minimum application rate of 0.65 inches per hour. They are primarily adapted to pastures or tall growing crops where rapid coverage is desired or acceptable. They are limited to soils with high intake rates.

(6) Under-tree low angle sprinklers are designed to keep stream trajectories below fruit and foliage by lowering the nozzle angle. Operating pressures vary from 10 to 50 psi, provide a wetted diameter of 40 to 90 feet, with a minimum application rate of 0.35 inches per hour. They are best used in orchards where the irrigation spray from other sprinkler types will damage soft fruit or where wind will distort over-tree sprinklers. and where available operating pressure is low or

s of systems.

pes of systems refer to the type of pipe used,
moved. The type of pipe and couplings required
:

(1) Buried pipe with the ability to withstand bursting and structural strength to withstand loading. This is referred to as a solid-set system.

(2) Pipe placed above ground that is rarely moved. Such pipe is usually aluminum or galvanized sheet steel. Semi-quick couplings with rubber gaskets that are compressed tightly in the joint are used.

(3) Fully portable aluminum or aluminum alloy pipe. Each length has quick couplings. Pipe units are usually 20, 30, or 40 feet in length.

(4) Combination of the above.

(b) A lateral is a single line of pipe with sprinklers connected at periodic intervals along its length. The supply pipes to which laterals are connected are called mains. The following are the common types of laterals, most of which utilize slow rotation sprinklers.

(1) Hand-moved System

The portable lateral pipeline mounted with sprinklers is set at one location until the desired irrigation is obtained. The lateral pipeline is then disassembled and moved by hand from this location to another location and the operation repeated. The system is, therefore, a set-type system. Quick-coupled aluminum pipe is the best for most portable laterals. This is generally the cheapest type of system. However, considerable labor is required for moving the portable pipe. Figure C0685.13 shows the general layout and operation of typical set-type distribution system. The water source is in the center of the field, although, it could be at another point with the main line located through the center of the field.

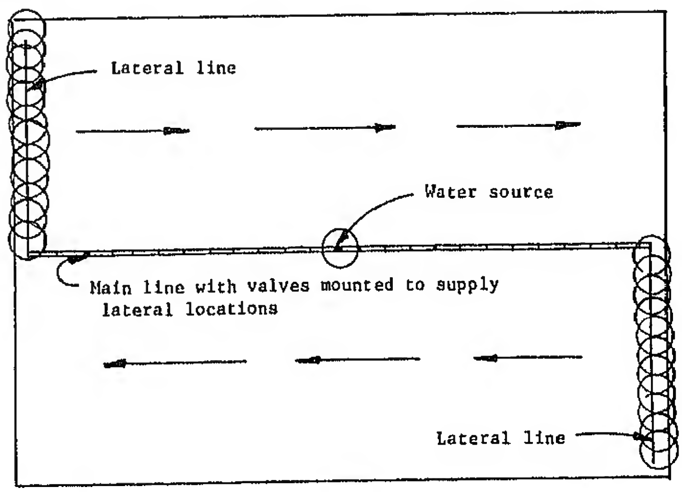


Figure C0685.13
Set-Type Irrigation
System

(i) Generally, to keep the labor costs as low as practical, the design should be such that the required irrigation is applied in either 7, 11, or 23 hour times of set to allow either 3, 2, or 1 sets per day with an hour allowed per setting to move the pipe.

(ii) Hand-moved systems have the advantage that they can be used on irregularly shaped fields and rolling terrain. They can use all nozzles from low to high pressure and can meet any intake requirements.

(2) Side-roll lateral.

(i) To decrease the amount and intensity of labor required; the lateral line is mounted on wheels. The pipe is the axle with the wheels usually spaced 30 feet apart, and the sprinkler located midway between the wheels. Wheels are available in different diameters with the largest wheels used for crops requiring the greatest clearance.

(ii) The lateral line is moved between sets by rolling the wheels. The distance between lateral sets depends on the size of the sprinklers, but usually between 60 to 80 feet.

(iii) On early models, a large lever with a ratchet was used to move the system. Today, most of the side-roll systems use air-cooled gasoline engines located near the center of the lateral line.

(iv) Because the pipe twists, a self-aligning riser is used to keep the sprinkler vertical.

(v) For greater coverage, side-roll laterals have been developed which use trailing sprinkler lines, each containing three or four sprinklers. This allows for set distances up to 300 feet. The field operation is the same as for a hand-move or conventional side-roll lateral except the coverage distance per set is considerably greater. Figure C0685.14 shows the operation of this system.

(vi) When a lateral line reaches the end of a field, it is either moved back to its starting point or to an adjacent field. In the case of the trailing systems; they must be picked up and transported separately. Provisions can be made to transport the trailing lines on the main lateral line, if not already provided by the manufacturer. The main lateral lines used with a trailing system often have the main lateral line support on some type of tower assembly to provide clearance for tall crops.

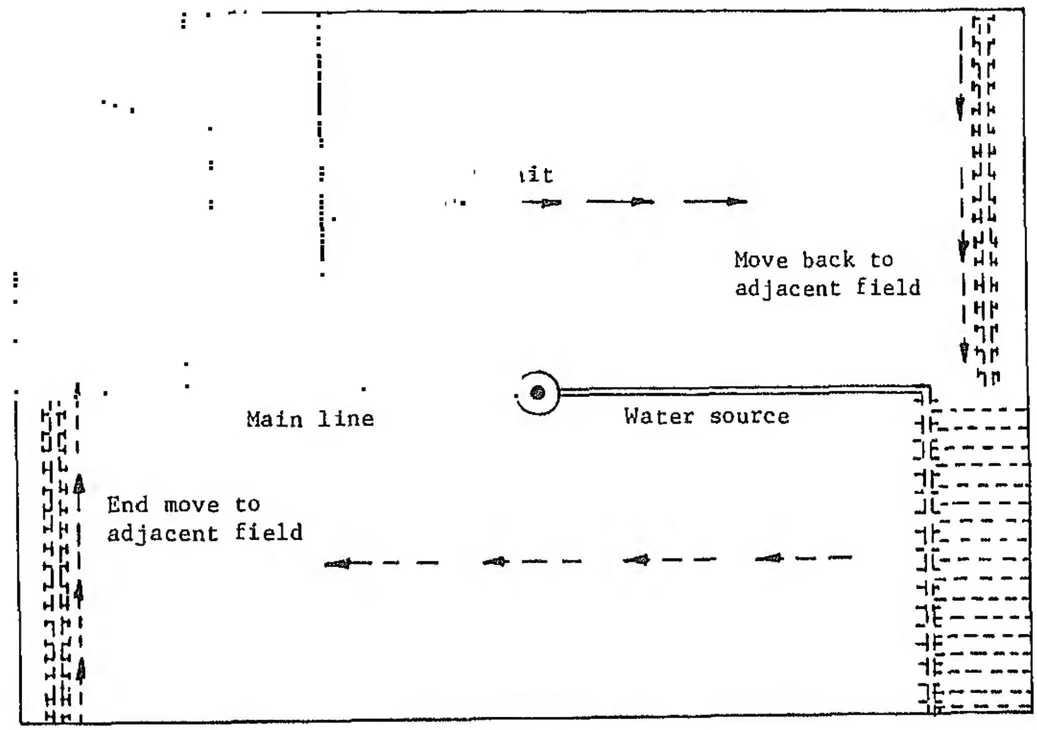


Figure C0685.14 Operation of Side Roll Wheel System with Trailing Line

(vii) The side-roll wheel systems should be such that the required irrigation is applied in either 7, 11, or 23 hours time to allow three, two, or one lateral moves per day for each lateral line, with an hour allowed to move a lateral line from one location to another. Here, again, as with hand-move systems, the seven hour time of set can be an unpopular set time because of the possible moves in the dark, and the additional time and attention needed for three moves per day. However, in a large multiple lateral system, if soil intake rate permits a seven hour lateral set time, there can be a savings on amount of lateral lines required.

(viii) Designs should be the same as for hand-move laterals. They can be used on any soil type suitable for sprinkler irrigation. Alignment may be difficult on undulating topography.

CO685.32(b)(3)(i)

(3) End-tow lateral.

(i) Another irrigation system using lateral sets, is the end-tow or tractor-move lateral. The lateral line has couplings semi-permanently fastened together. The lateral line may be mounted on skid pans or small wheels and towed from one set to the next. The main line which supplies the water for the system is located in the center of the field.

(ii) A turn strip 100 to 200 feet wide is provided so the lateral line can be turned as it is towed from one side of the field to the other. A typical system might have 60 foot sets so the lateral will need to be shifted 30 feet as it crosses the turn strip. This turn strip may be grass, or some harvestable crop, so that this land is not completely lost to production.

(iii) When the lateral reaches the last setting in the field, it is moved back to the starting position--the location of the first set.

(4) Rotating boom sprinkler.

(i) This sprinkler consists of pipe and nozzle arms that rotate about the center or balance point located on a 4-wheel mounted turntable. A tower and cable arrangement holds the boom in place. The boom rotates by water pressure, using a jet action controlled by various nozzle arrangements, nozzle sizes, and water pressures. The arms are provided in a choice of lengths providing coverage of about 1 to 4 acres per setting. Application rates vary from about 0.4 to 0.8 inches per hour with the usual rate being approximately 0.5 inch per hour. The unit can be pulled ahead to a new setting by a tractor attached to the boom carriage by a cable that is sufficiently long so that the tractor operates on dry ground. As the boom moves ahead, the feeder pipeline can be picked up and placed on the trailer that supports the boom. Settings should be such that a triangular pattern results with adjacent lanes.

(ii) Because of the large wetted diameter of coverage, there is some problem with wind distortion of the distribution pattern. Wind also affects rotation speed of the boom. Since water discharges from the nozzle at a uniform rate, any variation in rotating speed will upset the sprinklers' distribution pattern. The distance between lanes should be equal to the diameter of the boom plus 70 percent of the difference between the wetted diameter and the boom diameter.

(iii) Rotating boom sprinklers can be used on irregularly shaped fields. Application rates are too high for some soils.

(5) Volume gun sprinkler.

(i) The volume gun sprinkler consists of a single high capacity nozzle mounted on a 2 to 4-wheel trailer. The pump and power unit may also be mounted on the equipment, or it may be permanently placed at a central location. Sprinkler nozzles are usually larger than 3/4 inch diameter. Operating pressures exceed 90 pounds per square inch. Operating at less than the manufacturer's recommended pressure will cause uneven water distribution. Because volume guns produce large wetted diameter, it is difficult to obtain proper overlap of the sprinkler patterns. The distance between the lanes should be approximately 65 percent of the diameter of the wetted area. The sets should be such that a triangular pattern will result.

(ii) Volume guns can be used on irregularly shaped fields. Wind affects water distribution and alley ways are required for row crops. Volume guns are suited to relatively high intake rate soils. Application rates exceed 0.65 inches per hour.

(6) Continuous move sprinkler.

(i) Both the boom and the volume gun can be operated as a continuously moving unit. The speed of the sprinkler can be varied and adjusted according to the amount of water to be applied.

(ii) The flexible supply hose must be strong enough to withstand high operating pressures and being towed when full of water. Thus a special, expensive type hose, is needed for continuous move sprinklers. Periodic replacement of the hose is a significant maintenance cost item and should be considered in the purchase of this type of sprinkler.

(iii) Continuous move booms or volume guns have the same advantages and limitations as their stationary counterparts, but rectangular field coverage is obtained. The flexible hose has the added disadvantage of high friction loss.

(iv) Figure C0685.15 shows the operation of a boom sprinkler with a continuous move. A winch is anchored at one end of the field and an air-cooled gasoline engine winds up the cable which tows the sprinkler at a continuous rate along the lane through the field. The flexible hose supplies water to the sprinkler from the main line in the center of the field. For a lane length of 1,320 feet, about 600 feet of hose is required. Water distribution with the continuous move sprinkler is considerably better than with a set-type. The overlap problem between adjacent sprinkler patterns in the lane is eliminated. The travel lane must be smooth and well maintained; otherwise an uneven pattern will result from a tilted sprinkler. Design requirements are the same as for rotation boom sprinkler.

(v) The power to move the sprinkler may be supplied by self-propelled equipment or by a motor mounted on the sprinkler trailer which winds a cable on a drum. The cable is anchored at the end of the field.

(vi) On some types of volume gun sprinklers, a sprinkler mechanism purposely does not water the area directly in front of it to keep a firm track for the sprinkler cart or trailer. As with the boom sprinkler, the overlap pattern between individual sets along the lane is eliminated; thus the distribution pattern is better than with the same sprinkler set at selected intervals.

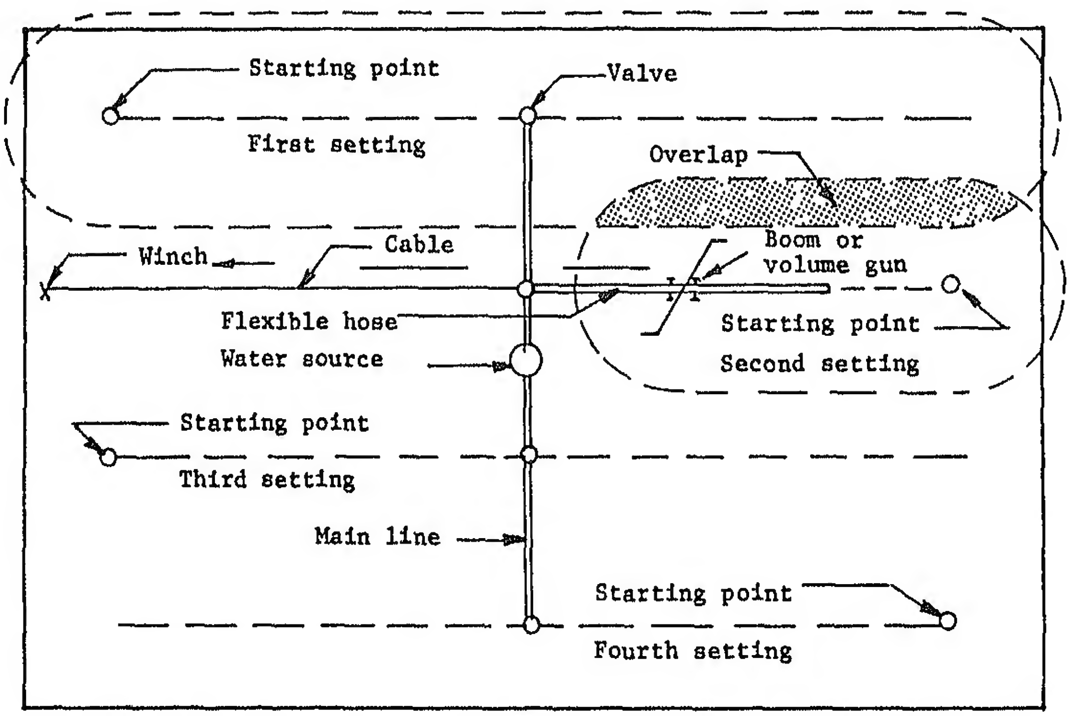


Figure C0685.15 Typical Continuous Move Boom Volume Gun System Layout

(7) <u>Center pivot sprinkler.</u>

(i) This system consists of a single lateral mounted on wheels and rotated about a pivot at the center of the field. The lateral pipeline is supported by towers spaced from 90 to 126 feet apart. Each tower has a drive mechanism to provide power to the wheels. The type of power varies with the manufacturer. Drive mechanisms can be electric motors or hydraulic systems using air, water or oil. Clearance height ranges from a minimum of 8 feet to 14 feet.

(ii) Water enters the lateral at the center hub and is distributed through sprinkler heads along the pipeline at variable spacings. Some center-pivot systems have a large volume sprinkler that rotates through only one-half circle at the end of the system.

(iii) The speed of rotation of the lateral is adjustable and may vary from 12 hours to 120 hours per revolution. Regardless of the speed of rotation, the rate of water application remains the same. The faster the speed of rotation, the less total water is applied per rotation. An average water application is approximately 1.0 inch. Speed is controlled by the end tower.

(iv) With the center-pivot a circular or square field is required. On a quarter section, approximately 135 of the 160 acres are irrigated. About 6 acres in each corner of the field will not be irrigated.

(v) Most center-pivot laterals use a large gun to fill in parts of the corners of a square field. The area covered by the big gun seldom receives as much water as the remainder of the field, and generally this is the area producing the poorest yields.

(8) Solid set laterals.

(i) The solid set system is popular for high value crops. With this system, the main line and the lateral lines remain in place during the growing season; sometimes they are set permanently with the lines buried. With other solid set systems, the lines are installed in the field after planting and remain there until harvest.

(ii) There are two types of solid set systems:

(a) A system where all of the laterals are operated simultaneously. This type may be modified to a rapid sequence system where water is applied for approximately 3 minutes to each one-fifth of the area, and the irrigated area is covered each 15 minutes until the desired application has been made.

(b) The automatic sequencing system, where a group of sprinklers operate the required time, then automatically shut off and another group turn on. This sequence is repeated until the field is irrigated.

(iii) Solid set systems have a low labor requirement and can be adapted to irregularly shaped fields. Investment costs are high and lateral lines may interfere with operations.

C0685.33 Design and evaluation of sprinkler systems operating in sets.

(a) System requirement. Sprinkler systems operating in sets require the moving of the laterals at specific intervals of time. In order to fit in with farm schedules, it is recommended that the time set be planned for seven-hour, eleven-hour, or twenty-three-hour periods of time which allows one hour per set for moving the lines and servicing the equipment.

(b) Sprinkler evaluation and design

(1) Readily available tables have been prepared to provide guidance for sprinkler system designs. These along with the following criteria will give data needed to recommend the use and design of systems:

(i) Design should be based on meeting the requirements of the most restrictive crop or combination of crops to be grown.

(ii) The maximum allowable variation in lateral line pressure should not exceed ± ten percent of the design pressure.

(iii) For selection of the most economical pipe size, the loss in the main line should not exceed 20 to 30 percent of the pressure at the pump, depending upon energy costs.

(iv) Alternate lines should be staggered to give best application distribution and should not be spaced more than approximately 0.6 times the wetted diameter of nozzles used.

(v) 1.0 psi pressure is equal to 2.31 feet of head.

(vi) 1 gpm applies 0.00221 acre-inches per hour.

(vii) Tables C0685.67 through C0685.77 provide data for design and evaluation.

(c) Example - Design of sprinkler system operating in sets

(1) The following example is not intended to show the complete design procedure but only a guide to general determination of suitability of a specific system and approximat size requirements for final design and to guide the user in equipment selection. For more specific design criteria, refer to Chapter 11, Section 15 of the NEH, Sprinkler Irrigation.

(2) Problem: Design a sprinkler system to meet the specific design requirements.

(3) Given:

(i) Location - Rocky Ford

(ii) Field - Dimensions as shown in Figure C0685.16

(iii) Soil - Haverson loam, less than 2% slope

(iv) Crop Alfalfa

(v) Water Supply - well at center of west side of field. Well is rated at 1,000 gpm.

(vi) Operator wants two sets per day (11 hour) and a spacing of 40'x 60'.

(vii) Average wind velocities during the growing season ar 4-8 mph.

(4) Sprinkler System Design

(i) Allowable application rate - From Table C0684.2 alfalfa has a 6 foot rooting depth, and Management Allowed Deficiency (MAD) for alfalfa is 50%.

(ii) From Section C0681.20, the water holding capacity for Haverson Loam (HAV) to five feet is 9.60 inches. Since HAV consists of stratified clay below 4 inches it is safe to assume that roots will not go to 6 feet as indicated in Table C0684.2. Use 5 foot root zone. Table C0685.70 suggest an application rat of 0.30 in/hr.

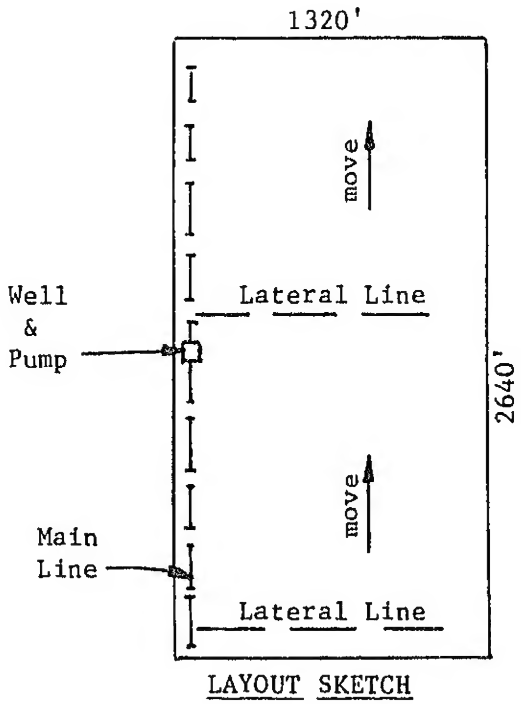


Figure C0685.16 Sprinkler System Layout

(iii) Since MAD is 50%, the moisture to be replaced is 9.60 (0.5) = 4.80 inches.

(iv) Table C0685.71 (2) recommends a nozzle size of 3/16 inch for a spacing of 40 x 60 and an application rate of 0.3 in/hr. Operating pressure is 50 psi and CU is 83%. This is above the 75% recommended for deep rooted crops.

(v) From Table C0683.52(a), with 4 and 5 inch applications, the peak daily consumptive use for alfalfa is found to be 0.32 inches.

(vi) Determine sprinkler application efficiency. From Table C0685.71(2), the expected CU is taken as 83%. From Figure 11-17, p. 11-24, Chapter 11, NEH Section 15 and daily consumptive use of 0.32 inches find "Re" to be 0.90. Then:

Efficiency = 83(.90) = 75% or
Use Table C0685.69 with over 3" application and
0.3 in/hr.

(vii) Allowable irrigation frequency
Net application/CU = 4.8/0.32 = 15 days

(viii) Determine net and gross application rates.

Net = 4.8/11 hours = 0.44 inches per hour
Gross = 0.44/.75 = 0.59 in./hr > 0.3 in./hr allowable

Try one set per day (23 hr.)

Net = 4.8/23 = 0.21 in./hr
Gross = 0.21/.75 = 0.28 in./hr < 0.3 in./hr OK

<u>One set per day is recommended</u>

(ix) GPM per nozzle

$$= \frac{0.28 \times 40 \times 60}{96.3} = 7.0 \text{ gpm}$$

From Table C0685.75 find 3/16" nozzle at 50 psi produces 7.2 gpm or check manufacturers references where a Rainbird 30 BW - TNT with 3/16" nozzle produces 7.18 gpm at 50 psi.

(x) Check wetted diameter for proper coverage. From National Handbook of Conservation Practices Standard 442:

spacing on lateral = 50% of D_w
spacing on mainline = 60% to 65% of D_w
Wetted diameter (D_w) is 100' (Rainbird)
Allowable spacing S_l = 0.5(100) = 50'
Allowable spacing S_m = 60'-65'
40 x 60 is adequate.

(xi) Number of Nozzles per lateral

N = 1320'/40 = 33 nozzles

(xii) Number of laterals required

$$\frac{L}{S_m(\text{set/day})(\text{days})} = \frac{2640}{60(1)(15)} = 2.93 \text{ laterals}$$

<u>3 laterals are required</u>

(xiii) Number of risers

$$\text{Risers} = \frac{\text{Mainline length} - (1/2 \text{ Riser spacing } (2))}{\text{Riser spacing}} + 1$$

$$= \frac{2640 - (30 \times 2)}{60} + 1$$

$$= \underline{44 \text{ risers}}$$

(xiv) System water needs
Qgpm = 3 laterals x 33 nozzles x gpm/nozzle

= 3(33)(7.18) = <u>711 gpm</u> < 1000 gpm OK

(5) Lateral Design

(i) Flow in lateral
Qgpm = 33(7.18) = 237 gpm

(ii) Allowable pressure variation in lateral lines is plus or minus 10 percent. For 50 psi we have a range of 45 to 55 psi. A variation of 10 psi is equivalent to 23.1 feet of head. For 33 heads per lateral the multiple outlet factor F is 0.36 from Table CO685.72. The allowable loss per 100 feet then:

$$H_f = \frac{23.1\ (100)}{1320\ \ (.36)} = 4.861 \text{ ft/100ft}$$

From Table CO685.73 a 4 inch aluminum pipe will carry 240 gpm with a head loss of 3.90ft/100ft.

<u>Use 4 inch aluminum laterals</u>

Actual headloss in lateral

$$H = \frac{3.90(1320)\ (0.36)}{100} = 18.5 \text{ ft or } 8.0 \text{ psi}$$

(6) Mainline Design

(i) With a three lateral operation, the maximum head loss is generated when the laterals are in the following position along the mainline.

1/3Q = 711 gpm
1/3Q = 474 gpm
1/3Q = 237 gpm

(ii) Actual mainline length; field length is 2640 feet. First riser is 30' in from the field edges. Length then is 2580 ft. Length of segments then become 860'.

(iii) Assume main line material to be PVC. Use SDR 32.5 (125 psi). For initial sizing limit velocity of 5 fps.

$$d = 12[(4Q/450)/3.14V]^{0.5}$$
$$d_1 = 12[4(711/450)/3.14(5)]^{0.5} = 7.612$$
$$d_2 = 12[4(474/450)/3.14(5)]^{0.5} = 6.215$$
$$d_3 = 12[4(237/450)/3.14(5)]^{0.5} = 4.395$$

Try 1720' of 8" diameter pipe and 860' of 6" diameter pipe.

(iv) Friction head loss restricted to 20% of the sprinkler operating pressure on the mainline. Then loss in the 8" line is:

$$f_1 = 0.0426\ Q^{1.85}/d_i^{4.87} = \frac{0.0426(711)^{1.85}}{(8.094)^{4.87}}$$

$$= 0.304 \text{ psi/100ft}$$
$$f_2 = 0.143 \text{ psi/100ft} \quad \text{for 474 gpm}$$
$$f_3 = 0.144 \text{ psi/100ft} \quad \text{for 237 gpm and 6.217" dia.}$$

$$\text{Total head loss} = 0.304(8.80) + 0.143(8.80) + 0.144(8.80) = \underline{5.2 \text{ psi}}$$

Try 6" PVC, rather than 8", for the middle third. The total headloss then is:

$$H = 0.304(8.8) + 0.519(8.8) + 0.144(8.8) = 8.5 \text{ psi}$$

This will work provided V is kept below 5 fps.

$$V = \frac{.407(474)}{(6.217)^2} = 4.99 \text{ fps}$$

For Mainline Line use:

880' - 8" PVC(IPS) SDR 32.5
1760' - 6" PVC(IPS) SDR 32.5

CO685.33(c)(6)(vi)

Figure CO685.17 Plastic Pipe (PIP) Friction Loss

Plastic Pipe (PIP) Friction Loss

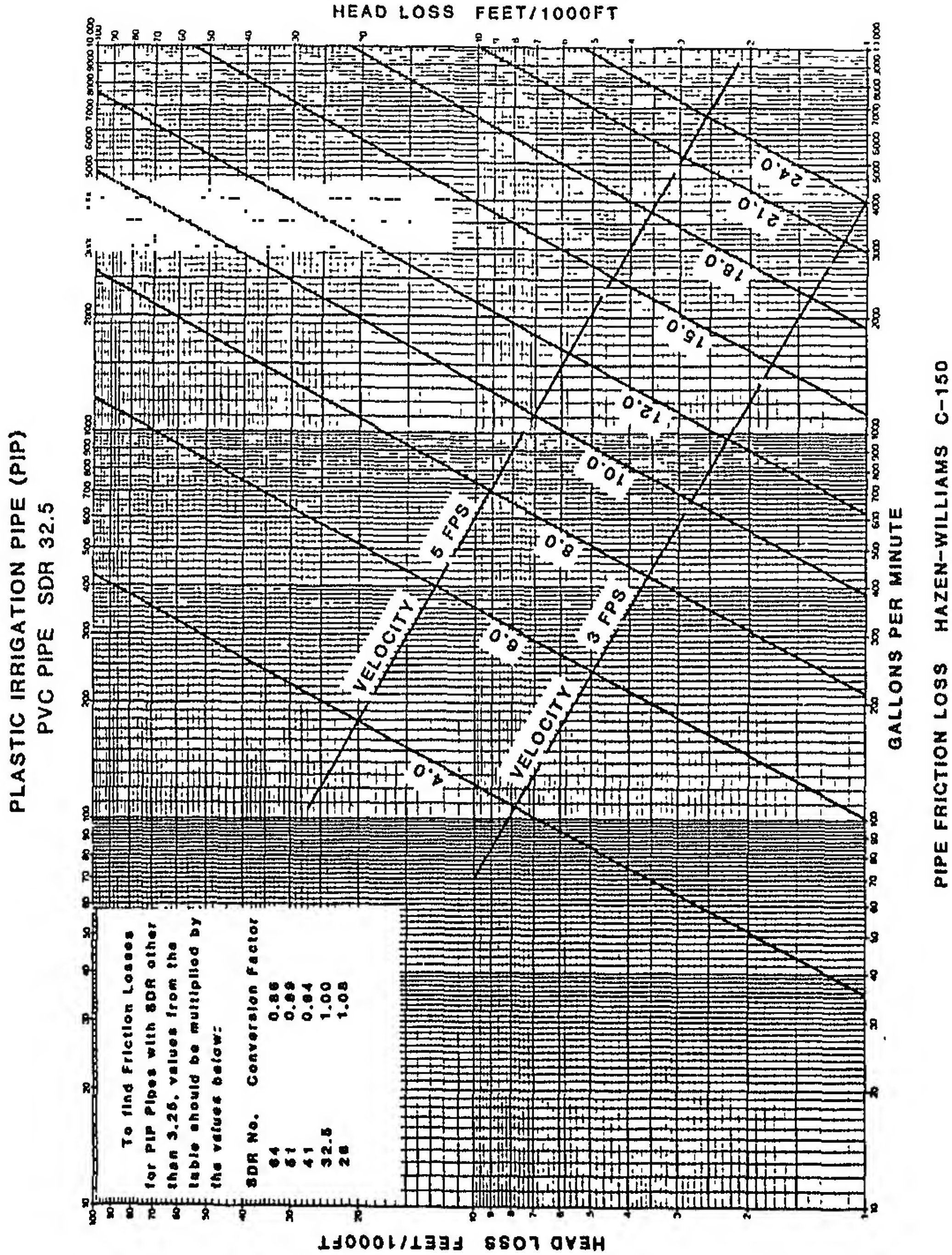
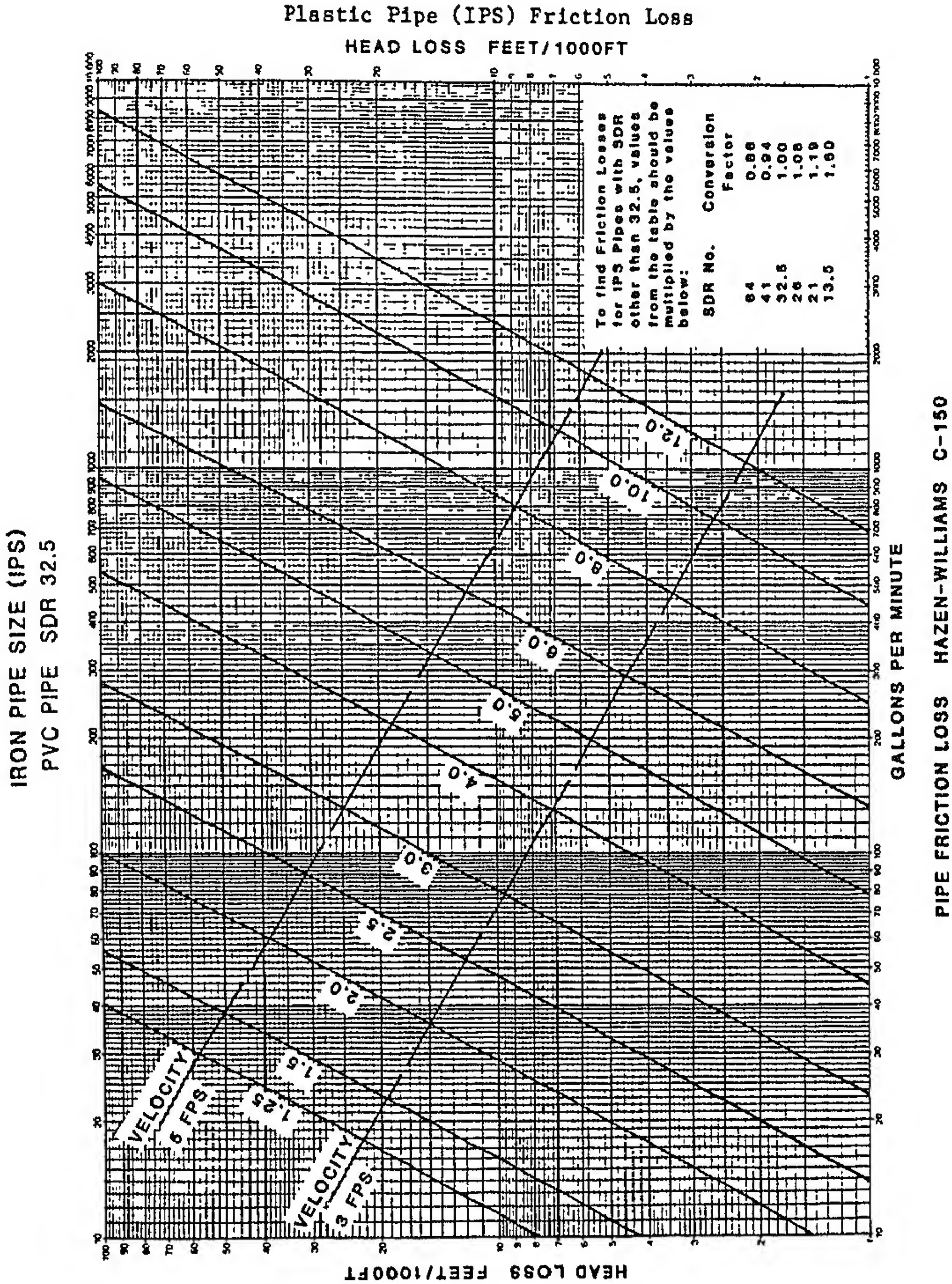


Figure C0685.18 Plastic Pipe (IPS) Friction Loss



(8) Example of a Worksheet

U.S. Department of Agriculture
Soil Conservation Service

IRRIGATION DESIGN

Owner IRRIGATION GUIDE EXAMPLE Date 2/31/00
Location Rocky Ford Acres 80
Resource Inventory:

Soils; Haverson loam less than 2% slope
Water holding capacity, ____ in/ft.
Soil depth, 6 ft.
Total available water, 9.6 inches
Maximum soil intake rate. 0.30 in/hour

Crops; Alfalfa
Moisture extraction depth, 5 ft.
Net Moisture to be applied, 4.8 in/irrigation
Peak period use rate, 0.32 in/day
Maximum allowable irrigation frequency, 15 days

Water Supply;
Source, Well (I.D., Co, well, etc.)
Amount available, 1,000 gpm

Sprinkler Design;
Application efficiency, 75%
Gross application per irrigation, 6.4 inches
Sprinkler setting, 23 hr.
Sprinkler;
Application rate, 0.28 in/hour (< soil intake rate)
Spacing, 40 ft. on lateral; 60 ft. on mainline
Discharge, 7.2 gpm/sprinkler
Nozzle Size, 3/16 inches by --- inch
Nozzle Pressure, 50 psi x 2.31 = 115.5 ft.
Wetted Sprinkler Diameter, 100 ft.

Note: Sprinkler spacing on laterals and mainline should not exceed the following spacing of the wetted sprinkler diameter.

Average Wind Velocity	Laterals	Mainline
Less than 5 MPH	0.5 Dia.	0.65 Dia.
5 MPH	0.5 Dia.	0.60 Dia.
10 MPH	0.5 Dia.	0.50 Dia.
Greater than 10 MPH	0.5 Dia.	0.30 Dia.

Lateral Design:

Lateral length, 1320 ft. (average, (typical), or maximum)
Sprinkler per lateral, 33 (average, (typical), or maximum)
Acres irrigated per lateral per day, _____ acres (average, typical, or maximum)
Laterals required, 3
Irrigation design frequency, 15 days (< maximum allowable irrigation frequency)
Total water requirements, 711 gpm (< amount available)
Laterals:
Material, Aluminum Pressure Rating, --

Q GPM	Dia. in.	Length ft.		h_f psi/100'				h_f ft.		Elev. ft.		Pressure Loss, ft.
237	4	1320	x	1.7	x	2.31	=	51.8	±	0	=	51.8
			x		x	2.31	=		±		=	
Total pressure loss in lateral											=	51.8 ft.

Note: Allowable pressure loss in the lateral should not exceed 20% of the operating pressure of the lateral.

Mainline Design:
Material, PVC (SDR 32.5); Length, 2,580 ft.

Q GPM	Dia. in.	Length ft.		h_f psi/100'				h_f ft.		Elev. ft.		Pressure Loss, ft.
711	8	880	x	0.304	x	2.31	=	6.18	±	-	=	6.18
474	6	880	x	0.519	x	2.31	=	10.55	±	-	=	10.55
237	6	880	x	0.144	x	2.31	=	2.93	±	-	=	2.93
Total pressure loss in mainline											=	19.66 ft.

Note: For economical mainline design, the total pressure loss in the mainline should be between 5 and 15% of the pumping head.

Pumping Requirements:

Sprinkler discharge pressure, 115.5 ft.
Pressure loss in lateral, 51.8 ft. (Negative values not used)
Pressure loss in mainline, 19.7 ft.
Pumping head, 160.0 ft.
Miscellaneous friction loss, 11.6 ft. (Used 10% of nozzle pressure.)

Total dynamic head, TDH = 358.6 ft.

Estimated horsepower; HP;

$$HP = \frac{(711\ \text{gpm})\ (358.6\ \text{ft.})}{(3960)\ (0.8\ \text{efficiency})} = 80.5\ HP$$

Vertical turbine pump assumed at 80% efficiency.

(v) Actual lateral pressure at main line is:

$$P_m = P_a + 3/4\ P_f + P_r$$

Where

P_m = Pressure at main line end (psi)
P_a = Average operating pressure (psi)
P_f = Actual pressure loss (psi)
P_r = Pressure loss through risers
P_m = 50 + 3/4 (8.0) + 4/2.31 = 57.7 psi

(7) Horsepower Requirements

Total dynamic head is then:

Loss in lateral	=	57.7
Loss in mainline	=	8.5
Miscellaneous losses (10% of operating pr.)	=	5.0
total		71.2 psi

If we assume the pumping level is 150 feet deep and 10 feet of loss on the suction column the horsepower needs are computed as follows:

$$HP = \frac{\text{GPM x Head (ft)}}{\text{3960 x Efficiency}}$$

$$= \frac{711\ [71.2(2.31) + 160]}{3960\ (.8)}$$

$$= 72.8\ \text{Hp}$$

CO685.34 Design concepts for center-pivot sprinkler systems.

(a) Center-pivot systems are unique in that the rate of speed and the application rate increase as the distance from the pivot point increases. Therefore, there is no one application rate for these systems. The operating characteristics of these systems, for purposes of the irrigation guide, can be evaluated by determining the gross application rate in the area between the outer two towers approximately 3/4 of the distance out from the hub. If properly designed, the application will be relatively uniform over the remainder of the field and the rate of the application will decrease toward the pivot center of the system, and therefore, be satisfactory if the outer end is within the soil intake limitations.

(b) The speed of rotation of the center-pivot system varies from 12 hours to 120 hours per revolution. With the center-pivo self-propelled system the application rate (iph) is the same regardless of the speed of rotation. However, the faster the rotation speed, the less total water applied per rotation. An average rotation speed is approximately 18 to 72 hours per revolution, and an average water application is approximately 0.5-1.0 inches. The speed of the center-pivot, self-propelled sprinkler, is controlled by the end tower, called the master tower. A system of alignment controls keeps the other towers in line with the end tower. The discharge of evenly-spaced sprinklers is directly proportioned to the radial distance from the center. Therefore, the application rate varies continuously increasing with increasing radius from the center.

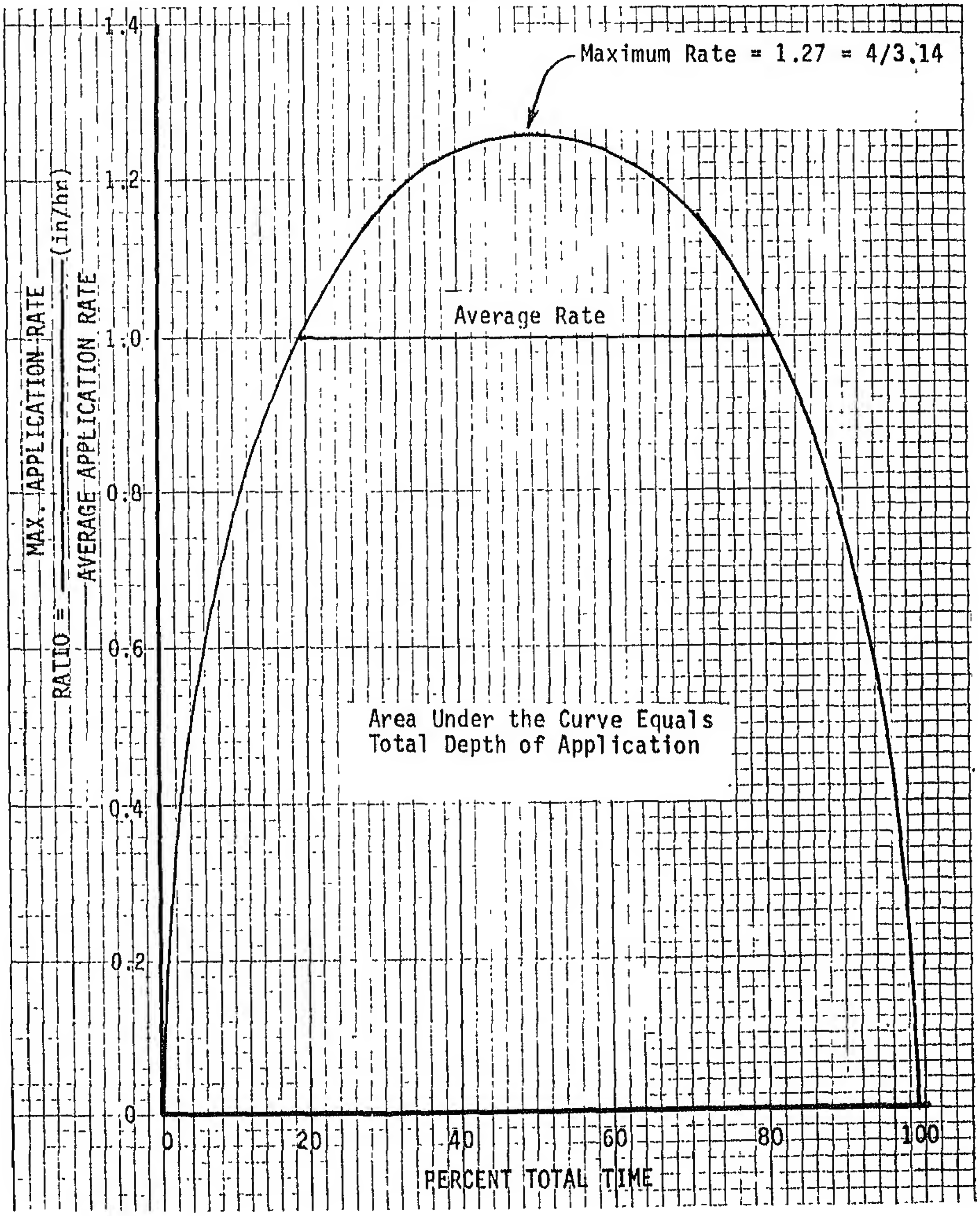
(c) Many of the sprinklers used on center-pivot systems apply a stationary pattern similar to an ellipse. The application rat at a given distance from the pivot begins at zero at the time when the sprinkler pattern reaches a given point, reaches a maximum when the sprinkler line is directly above the point, and decreases again and becomes zero when the trailing edge of the pattern passes the point. The depth applied at the given point is represented by the area under the application rate versus tim curve. To achieve a uniform depth of application over the enti area of the circle, application rates must increase as the distance from the center increases. The radius of the sprinkler pattern does not increase as rapidly as the speed of travel for given point on a sprinkler lateral. The actual time of application decreases as the distance from the pivot increases. Thus, the application rates increase with distance from the piv to maintain the same application depth. This is illustrated in Figure C0685.19 which shows a plot of time versus the ratio of maximum application rate to average application rate in inches per hour.

(d) Some center-pivot systems use a large partial-circle, hydraulic revolving sprinkler called a large or big-gun at the end of the lateral line to fill in parts of the corners of the field. The area covered by the big-gun seldom receives as much water as the remainder of the field and generally produce lower yields. If run-off occurs at the outer end of the lateral line. it may be enough to lower yields due to lack of adequate soil moisture.

(e) Some problems associated with center-pivot irrigation systems have been identified and the following recommendations made to solve them.

C0685.34(c)

Figure C0685.19 Relationship of Ratio of Maximum Application Rate to Average Application Rate vs. Time of a Moving Sprinkler System (Center Pivot).



(1) Crops can be planted in circular rows around the center-pivot system rather than in straight rows. This circular planting results in 94 percent of the land having longer rows than traditional fields. Circular planting reduces wheel traction problems for the machine and increases irrigation uniformity.

(2) The wheel traction problem can be lessened by building ridges for the wheels to run upon. In this way, the wheels do not run in excessively wet or muddy soils as they often do when water is allowed to run into the tracks. On a bare field, the center-pivot system is run around a full circle marking the wheel tracks. A furrow is then plowed from the inside throwing soil toward the outside and over the wheel track. Then a furrow is plowed from the outside throwing soil toward the inside and over the wheel track. This builds a ridge for the wheels to run on. Next, the ridge top is flattened so the wheels do not slip off. If it isn't flattened, the wheels may slip off and the main irrigation pipes may be broken. With the ridge tops flattened, the center-pivot is run around a second time to mark the wheel tracks and, if necessary, the ridge building process is repeated.

(3) The irrigation uniformity can be improved by smoothing the land under the center-pivot system to remove any steep slopes. On most sections the land is rolling which decreases the infiltration rate. Best results are achieved using a tillage and planting system developed as part of the project. In it, row crops are planted on trash-free beds with the crop residue being partially incorporated into the furrows between the beds.

(4) Pre-irrigation should be used under center-pivot systems. The idea is to fill the root zone with moisture before working the soil and planting the crop. This helps create a deep-root system and stores moisture for use during the periods when the sprinkler system is unable to keep up with the crop needs.

(5) Most farmers tend to run their center-pivot irrigation systems too fast. Frequent irrigation seals the soil, reduces infiltration and increases evaporation. Overall, the irrigation frequency depends upon the soil texture.

(f) Research has shown that the slower the movement of a pivot the higher the potential run-off because the water application at the outer reach of the pivot exceeds the intake rate of the soil which is decreasing with time of application (See Figures C0685.20 and C0685.21). The following recommendations address the majority of run-off problems.

C0685.34(f)(1)

(1) Use soil moisture measurements to determine when next to irrigate.

(2) Use artificial storage such as pitters or dikers.

(3) Seed winter wheat early so as to provide a high level of ground cover during spring irrigations.

(4) Avoid burning residue.

(5) Use surface roughening such as chiseling and leaving a cloddy condition.

(6) Use subsoiling to break up tillage pans and other restrictive layers. This operation must be done in dry soil conditions to be effective.

(7) Reduce operating flow rate (gpm's) of the system and switch to a low water use crop.

(8) Start spring irrigations when there is at least 20% ground cover.

(9) Switch to a no-till farming operation.

(10) Practice minimum tillage to leave at least 1500 lbs of residue.

(11) Leave sufficient soil moisture reserve for winter. Winter moisture will save that much on system operation as well as reduce run-off and soil loss in the spring.

C0685.35 Design procedure.

(a) The design of a center-pivot sprinkler system is complex. Most systems are computer designed by the company doing the installation. Therefore, the following procedure should be used to determine design adequacies relating to maximum application rates and depths of water applied by center-pivot sprinklers. NEH, Section 15, Chapter 11 revised, Sprinkler Irrigation, reviews design procedures. Other design requirements relating to main supply line, if any, are to be done by standard procedures. The brake horsepower requirement may also be calculated. To determine suitability, it is first assumed that the system is properly designed so that a uniform depth of application is obtained.

(b) A properly designed pivot provides a high discharge uniformity and must be evaluated against:

(1) The ability to satisfy crop needs.

(2) The impact on the soil resource (whether erosive or not) and to what degree.

(c) The ability to satisfy crop needs should be evaluated first. A center-pivot is inherently a low volume application system. It is often considered a deficit irrigation device. This means that at times during the growing season, insufficient water is applied to replace crop use. The moisture is extracted from the soil profile during peak use and is replaced by the system when the peak has past.

Sizing a minimum allowable volume for a pivot is a function of the crop need and soil water holding capacity. The following examples illustrate this point.

(1) Determine the volume of a system to meet the peak daily consumptive use:

Known: Crop - Corn
Soils - Haxton Sandy loam
Area - Washington county
Acres - 132 acres
Hours per cycle - 72 hours (3.0 days)
Application Efficiency - 70%

Solution: Consumptive Use - From Table C0683.50(z)
CU @ Wray is June - 4.26"; July - 7.73"; August 7.22"
Assume 1" Net Application
Daily CU = 0.32" (Table C0683.51, and CU = 7.73)
Actual needed application = 0.32 (3.0 days) = 0.96"

$$\text{Required system capacity } (Q) = \frac{453\ Ad}{HE}$$

Where: d = daily consumptive use
A = Acres irrigated
H = Hours operated per day (24 continuous)
E = system efficiency

$$Q = \frac{453\ (132)(0.32)}{24\ (0.70)} = 1140 \text{ gpm}$$

(2) Determine the volume of a system designed to use soil moisture reserve and an average monthly crop use with the same data as in (1).

C0685.35(c)(2)(i)

Solution: From Table C0684.2 Corn has a rooting depth of 4 feet and a management allowed deficiency of 50%

Total WHC at 4 ft. = 7.82"

Available soil reservoir = 7.82 (0.5) = 3.91"

(i) The system must have the ability to fill the root zone before deficit starts and the ability to catch up after the peak. Therefore, it is necessary to consider the months adjacent to the peak. At 1" replacement.

CU June = 0.17"/day
CU August = 0.30"/day

Evaluate peak month using deficit July 7.73" - 3.91" = 3.82 application needed. July has 31 days; allowing 3 days system down time net irrigation days are 28.

$$\text{Daily application need} = \frac{3.82}{28} = 0.14\text{"/day}$$

(ii) If a system was designed to use soil deficit in July it could be designed for 0.14"/day, it is possible that the soil would be at its allowable deficit of 50% when another peak situation could occur. Design for 0.14"/day, then

$$Q = \frac{453\ (132)(0.14)}{24\ (0.70)} = 500\text{ gpm}$$

(iii) Use of this procedure is considered risk design and should only be considered where high levels of irrigation water management can be assured. The landowner needs to be totally aware of the element of risk involved.

(d) The ability of the center pivot system to apply water at a rate that can be absorbed by the soil is a function of the system's application rate and the soil intake characteristics. In Figures C0685.20 and C0685.21, the intake characteristics of a soil are shown as a function of rate (inches per hour) over time. As previously discussed the application rate of a center pivot is fixed regardless of time; only applied volume changes. When the application rate occurs outside of the soil intake curve, a potential for excess application occurs (Figure C0685.22). Various factors influence the degree of potential excess application.

(1) The basic intake rate of the soil. Generally, the higher the degree of fines (silt and clay) in soil, the slower the intake rate. Faster intake occurs in coarse grained (sands and gravels) materials with few fines.

(2) Center pivot packaging influences how the water is applied to the soil. Some of these influences are:

(a) Wetted width that the discharge is applied over.

(b) The size of water droplet impacting the soil surface. Research has shown that the larger the droplet being discharged, the greater the energy impacted to the soil surface. This energy has the ability to compact and seal the soil surface. On fine textured soils, this has significantly lowered the intake rate of the soil.

(e) Computer models are available that evaluate the impact of a center pivot system upon the resource and cultural base. These models should be used for evaluation. A simplified approach is presented for evaluation if this is not possible.

(1) Given: Maximum Radius Irrigation = R = 1320 ft.
Capacity of the System = Q = 1260 gpm
Systems for Evaluation:
a. 360^o Spray - Single Nozzle
b. Standard High Pressure Impact
Soils: Havre loam
Intake Rate = iph = 0.70
Cycle Time = Hrs = 60 hours (2.5 days) per revolution

(2) Solution: Field experience indicates that the characteristics of a center pivot at 3/4 of its wetted length is an indicator of a field average condition. If excess application exists at the 3/4 point, it gradually diminishes toward the pivot and drastically increases towards the outer edge.

(i) Data are needed on the nozzle wetted width at the 3/4 point. This may be retrieved from a design printout or field investigation and then using Table C0685.75. If this data are not available, the the following Table can be used.

CO685.35(e)(2)(i)

System	Operating Pressure	Wetted Diameter
Typical High Pressure Impact	75+ psi	160 feet
Medium Pressure Impact	50-75	130 feet
Low Pressure Impact	35-50	100 feet
360 Degree Spray	20-35	30 feet
180 Degree Spray	20-35	15 feet
Spray Boom	20-35	120 feet

From the Table System A width = W = 30 feet
System B width = W = 160 feet

(ii) Determine the time of concentration (T_c) of water being applied over a given point.

$$T_c = \frac{W \times Hrs}{4.7 \times R}$$

Where W = nozzle wetted width (ft)
R = radius irrigated (ft)
HRS = hours per revolution

$$\text{System A } T_c = \frac{30 \times 60}{4.7 \times 1320} = 0.29 \text{ Hrs}$$

$$\text{System B } T_c = \frac{160 \times 60}{4.7 \times 1320} = 1.55 \text{ Hrs}$$

(iii) Determine the peak application rate (PAR)

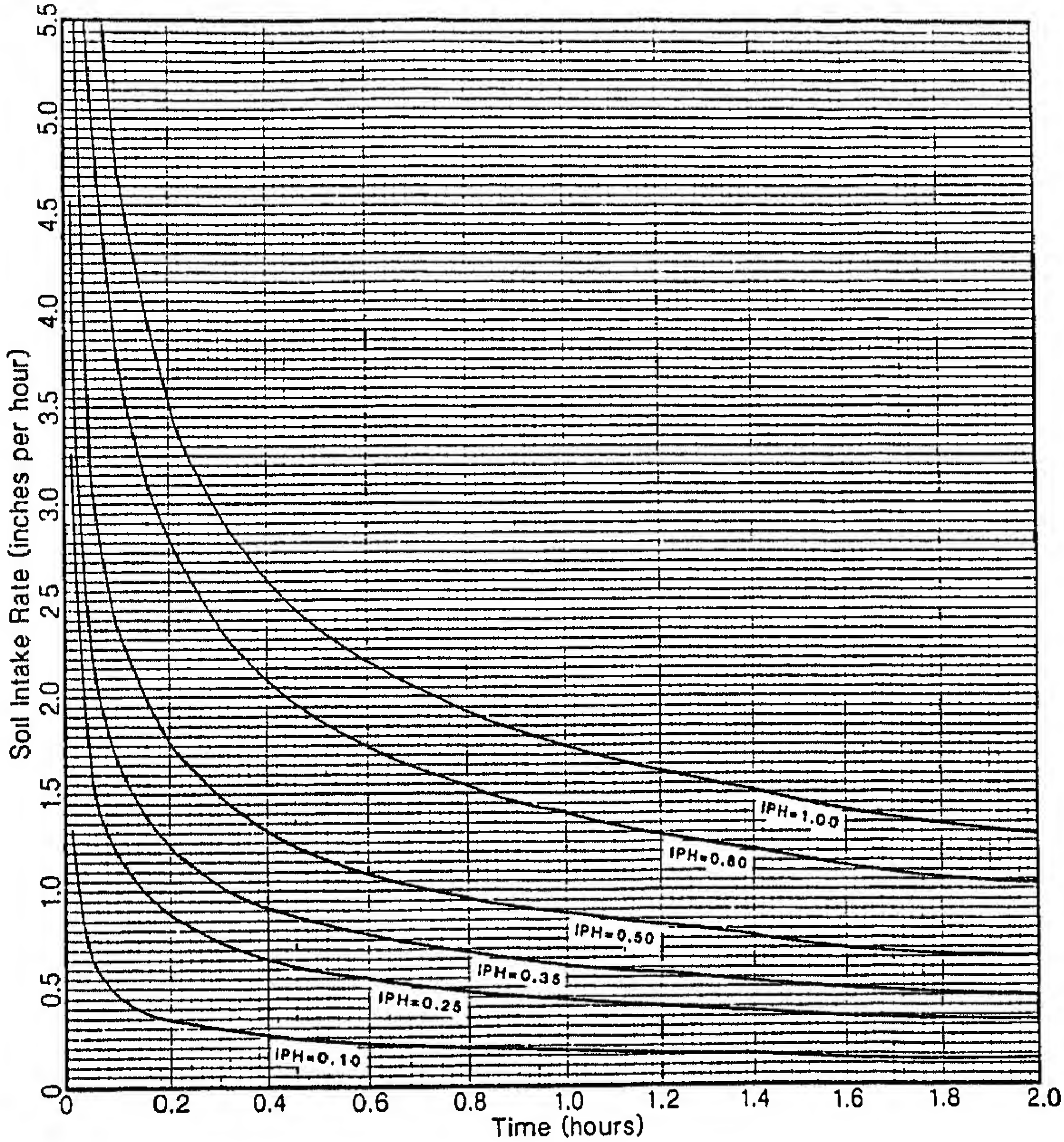
$$PAR = \frac{183.75 \times Q}{R \times W}$$

$\frac{60}{\times 30}$ = 5.85 inches per hour (iph)

$\frac{260}{\times 160}$ = 1.10 inches per hour (iph)

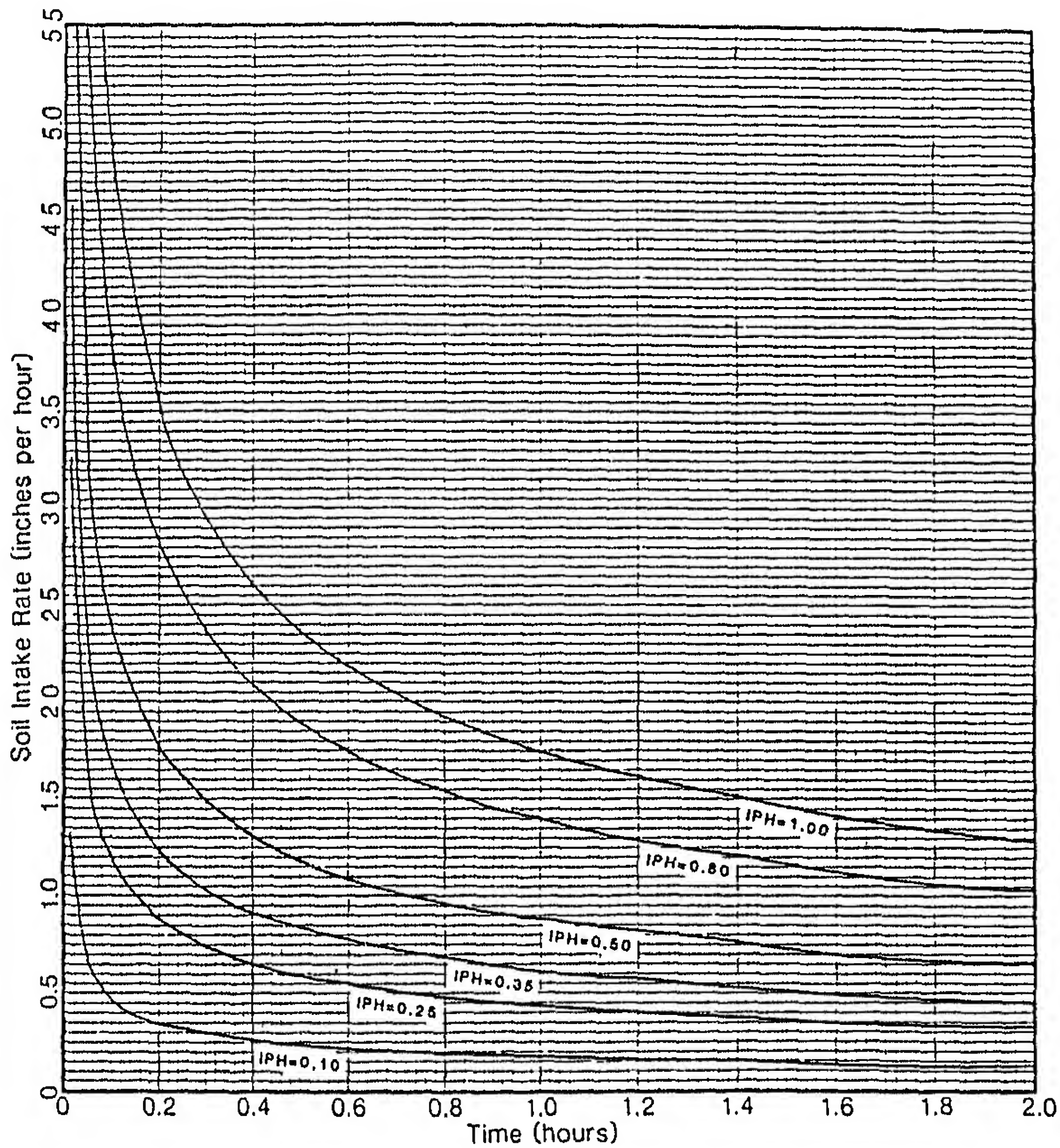
C0685.35(c)(2)(iii)

Figure C0685.20 Soil Intake Curves as a Function of Time
(Intake Rates = 0.20 - 0.75 IPH)



C0685.34(c)(2)(iii)

Figure C0685.21 Soil Intake Curves as a Function of Time
(Intake Rate 0.10 - 1.00 IPH



(iv) Potential runoff will not occur if the peak application rate (PAR) is less than the soil intake rate at a given time. The peak application would be expected to occur at 1/2 of the time over a point.

Time of peak application = $T_c/2$

System A = 0.29/2 = .145 Hrs
System B = 1.55/2 = .775 Hrs

(v) Determine if there is a potential runoff problem:

A. Mathematically - Soil intake rate at a given time
$I = 1.75 \times iph \times T^{-0.4364}$

System A $I = 1.75\ (0.70)\ (0.145)^{-0.4364} = 2.85$ iph

A runoff potential exists if iph of system > I of soil. 5.85 > 2.85 runoff potential <u>exists</u> with System A

System B $I = (1.75)(0.70)(0.775)^{-0.4364} = 1.37$ iph
1.10 < 1.37 runoff potential <u>does not exist</u> with system B

B. Graphically - Plot the peak application rate on the appropriate Figures (CO685.20 and CO685.21) against the time of concentration. The peak will occur at Tc/2. Develop a bell curve. Refer to Figure CO685.22.

C. Graphical plotting further aids in determining the volume of potential runoff compared to volume applied. From Figure CO685.22, it appears that a 360° spray system could produce approximately 15% runoff potential while the standard high pressure impact would produce none.

(vi) The degree of actual runoff depends on land slope, cultivation practices, and surface cover (both canopy and residues).

(f) If there is potential for runoff, the following items should be considered.

(1) The soil profile will not receive the water needed to satisfy crop needs.

(2) System applied chemicals will be moving with surface water movement

(3) Surface water movement generally creates erosion.

(4) concentration of runoff water can create downstream problems.

(5) A percentage of the pumping and power costs are lost revenue with no chance of yield benefit.

(6) Actual seasonal power cost may be significantly higher by pumping excess to make up for the crop needs lost to runoff.

(g) Research is presently addressing the degree of surface sealing that occurs due to the droplet energy of impact sprinkler systems. In the interim it is recommended that if surface sealing condition is experienced locally, the intake values (iph) in Part 681 Soils be reduced by 0.1 when evaluating impact sprinkler systems.

C0685.36 Design charts

(a) Tables, charts, and graphs have been developed to assist in this evaluation. They are in Subpart F - Tables of this section. Also, refer to NEH, Section 15, revised Chapter 11, Sprinkler Irrigation.

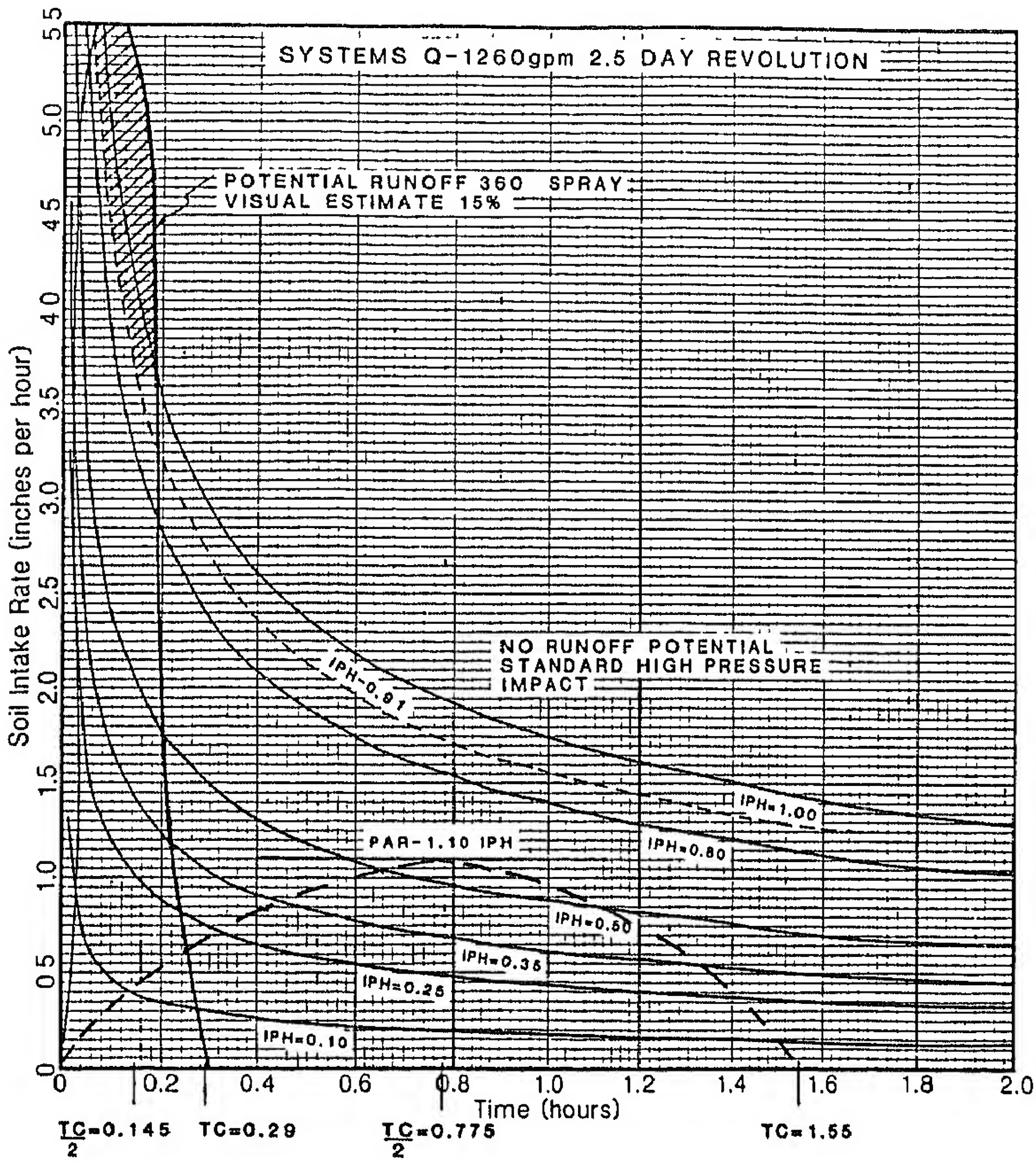


Figure C0685.22 Graphical Solution to Runoff Potential

Part 685 - Irrigation Methods and Design Criteria

SUBPART E - TRICKLE (DRIP)

C0685.40 Description.

Trickle irrigation is the slow application of water on or beneath the soil surface by drip, subirrigation, bubbler, and spray systems. Water is applied as discrete or continuous drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. Water is discharged from a pipe distribution network under low pressure in a predetermined pattern. The outlet device that emits water to the soil is called an "emitter." The shape of the emitter reduces the operating pressure in the supply line, and a small volume of water is discharged at the emission point. Water flows from the emission points through the soil by capillarity and gravity.

C0685.41 Types of systems.

(a) Drip

In drip irrigation, water is applied slowly to the soil surface as discrete or continuous drops or tiny streams through small openings. Discharge rates are less than 3 gallons per hour (gph) for widely spaced individual applicators and less than 1 gph/ft for closely spaced outlets along a tube (or porous tubing). Common types are:

(1) In line emitters, evenly spaced, at various available increments. Generally these are used in orchards and for ornamental plantings. These emitters generally have a uniform discharge over a specified pressure range.

(2) Emitters, insert type. These emitters are installed manually adjacent to the plant. They generally have a prefixed orifice size to discharge a given rate at a very tight pressure range. This type of emitter allows for insertion of more outlets as the water need of a plant increases. Attachment of a small tubing has been used to deliver water to a specific point. These emitters are also available in pressure compensating models to deliver water at a uniform rate over a wide pressure range. These emitters have been used on all trickle irrigated crops.

(3) Drip tape has small pinhole emitter points evenly spaced along the line. The ability to handle even discharge is governed by the type of tubing. Means of controlling discharge varies by manufacturer but basically there are three methods.

(i) Single tubing with evenly spaced holes (no pressure compensation).

(ii) A dual tubing with mainflow in one tube discharging a volume at a preset wide spacing into a secondary tube with narrower spaced outlets (limited degree of pressure compensation).

(iii) A triple tubing, based on the same principle as dual tubing, but with one additional chamber before discharge (fair degree of pressure compensation).

(b) Bubbler

In bubbler irrigation, water is applied to the soil surface in a small stream or fountain from an opening with a point discharge rate greater than that for drip but less than 1 gallon per minute (gpm). The emitter discharge rate normally exceeds the infiltration rate of the soil, and a small basin is required to control the distribution of water. A benefit to this method is the reduced filtration requirements due to the large discharge orifice.

(c) Spray

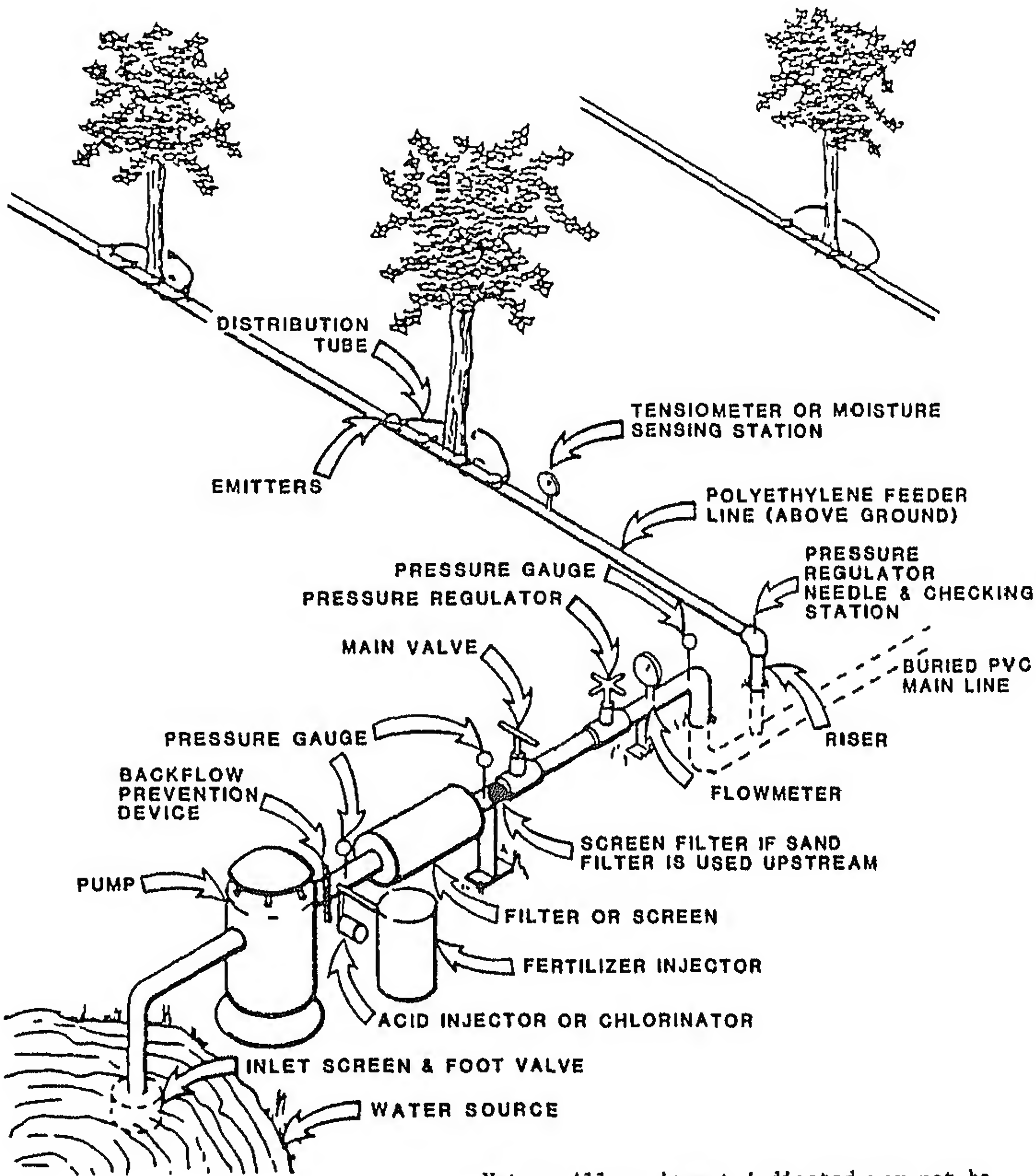
In spray irrigation, water is applied to the soil surface as a small spray or mist. The air is instrumental in distributing the water, whereas, in drip and bubbler, the soil is primarily responsible for distributing the water. Discharge rates in spray irrigation are lower than 30 gph (1/2 gpm). Since they function much like a sprinkler that is discharging a stream of water, close inspection is not needed to see if they are operating. They also have the ability to cover upwards of a 30 foot diameter. These emitters are often desired in a conversion from sprinkler to trickle in orchards due to the ability to provide water to the majority of the feeder roots established under sprinkler. Spray systems also exhibit a lower degree of plugging filtration equipment.

C0685.42 System components.

System components should include the following (See Figure C0685.23):

(a) Pressurizing point of prescreened water. May be a pump or gravity flow that generates between 5 and 20 psi pressure at the outlet emitter.

(b) Backflow prevention device if chemical injectors are located downstream and backflow conditions are possible. This is needed so as not to contaminate the water source.



Note: All equipment indicated may not be needed on each design.

Figure C0685.23 Typical Drip Irrigation System

C0685.42(c)

(c) Injectors as needed for supplying fertilizers or chemicals are needed to assure proper system operation (see Part C0685.48).

(d) Pressure gages upstream and downstream of the filter or screen. These are used to determine when the filter or screen needs cleaning or flushing by monitoring the pressure drop. The downstream gage is used to regulate delivery pressure needed for operation of the system.

(e) Filter or screen to remove sand, algae, trash, etc. that may plug the emitters. These devices are often used in combination. Good water quality along with delivery pressure are the most important elements in trickle irrigation to assure proper operation of the emitters in supplying the needed water. The filters or screens may be cleaned mechanically or automatically. Automatic operation is preferred and generally actuated when the pressure drop across the apparatus exceeds 10 psi.

(f) Main valve to regulate flow into the system. These valves are often sufficient to regulate the pressure downstream. If variation in flow or pressure can be expected, a pressure regulator should be placed downstream of the main valve.

(g) Flow meter and pressure gage should be placed downstream of the last valve to allow for regulation of flow and pressure entering the system.

(h) Mainlines and submains (Figure C0685.24) are generally buried PVC designed to run a block of lateral lines or polyethylene feeder lines at one time.

(i) Lateral lines and feeder lines are often mixed in terminology. A lateral line is generally buried PVC delivering water to a block of feeder lines or a buried line with small risers for spray systems. A feeder line is generally a polyethylene pipe, laid on ground, with a series of discharge emitters or orifices.

(j) Pressure regulator needle and check stations are commercially available and are recommended on the manifold lateral as a final fine tune adjustment. The check station resembles a tire valve stem that allows for ease of pressure checking. Use of this assembly often saves on system cost when compared to the cost difference between normal and pressure compensating emitters, the other alternative.

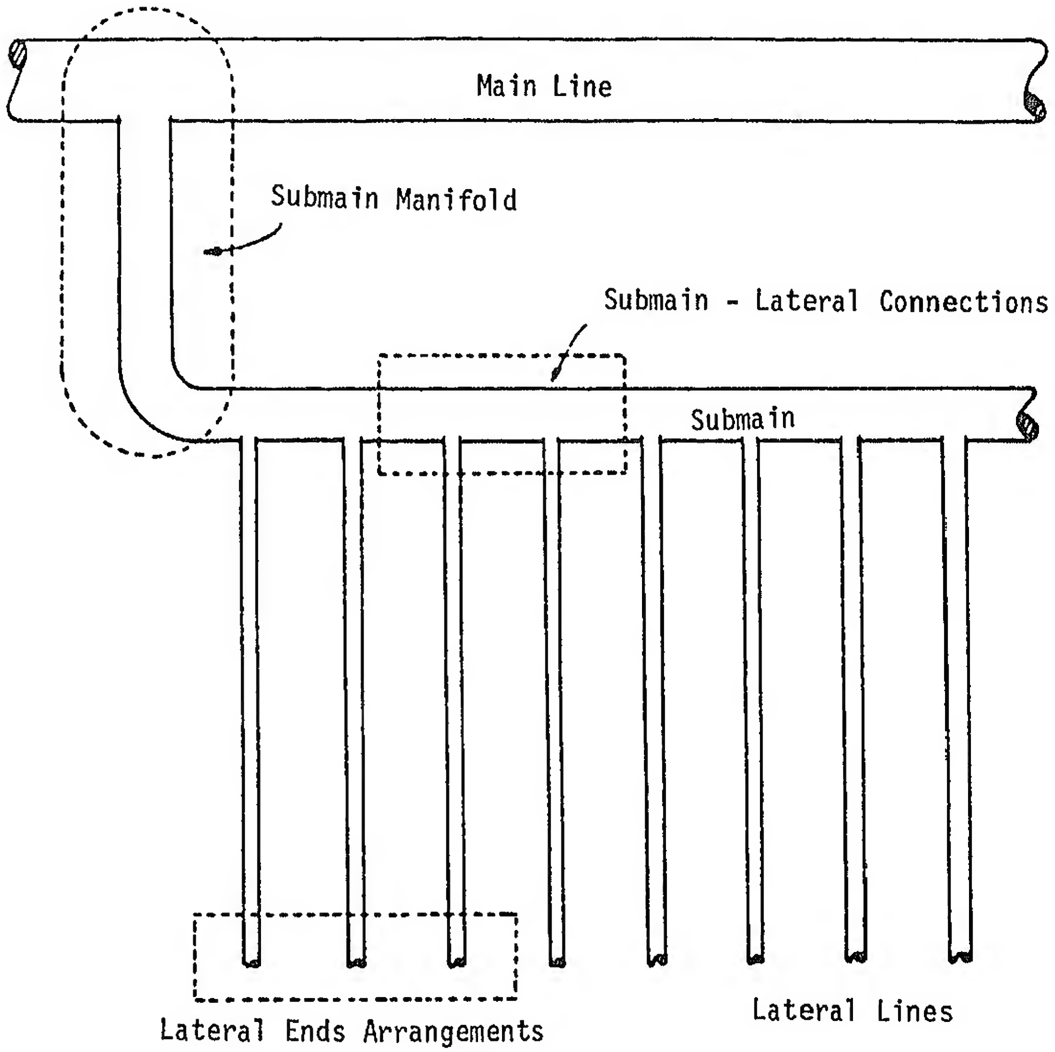


Figure C0685.24 Typical Trickle System Mainline, Submain, and Lateral or Feeder Line Detail

CO685.42(k)

(k) Moisture sensing station such as tensiometers or gypsum blocks, etc., to assure proper irrigation timing to meet soil and plant needs.

CO685.43 Design considerations.

(a) Drip irrigation systems are subject to problems of clogging, salinity build-up, poor soil moisture distribution and relatively high installation costs.

(1) Clogging. Clogging of the emitter is the most serious problem of drip irrigation. Properly designed filtration systems will generally protect the system from particle clogging. In addition, the selection of good quality water may prevent deposition of chemicals in the emitter passages or outlet, or biological growth in the pipe or emitter. Clogging can cause poor water distribution which in turn may damage the crop if emitters are plugged for a long period of time.

(2) Salinity. All irrigation water contains some salts which remain behind as the plants take up water. Due to the amount of water applied, these salts are pushed towards the edges of the wetted soil. Applying more water than the plants consume, and using supplemental applications of sprinkler or surface irrigation may be necessary to prevent critical levels of salt build-up where rainfall is insufficient for leaching.

(3) Moisture distribution. Drip irrigation normally wets a part of the potential plant rooting area. Crop systems are generally limited to this area of moisture surrounding the emitter. The extent of this volume is a function of the emitter discharge, distances between emitters, and soil type. Distribution of moisture should be a major consideration in design.

(4) Costs. The equipment and filtration needed for drip irrigation causes the costs to be high. The per acre costs are generally affected by filtration costs. Base costs for filtration are relatively the same for 20 acres as they are for 40 acres.

C0685.44 Design concepts.

(a) A primary objective of drip irrigation system design is to provide sufficient flow capacity to adequately irrigate the least watered plant. Application uniformity depends on uniformity of emitter discharge. Non-uniform discharge is caused by pressure differences due to friction loss, elevation, variations between emitters due to manufacturing tolerances and clogging.

(b) The designer of a trickle irrigation system has to make a rational choice about the duration of application, the number of emitters per plant, and the discharge per emitter that will give the best irrigation.

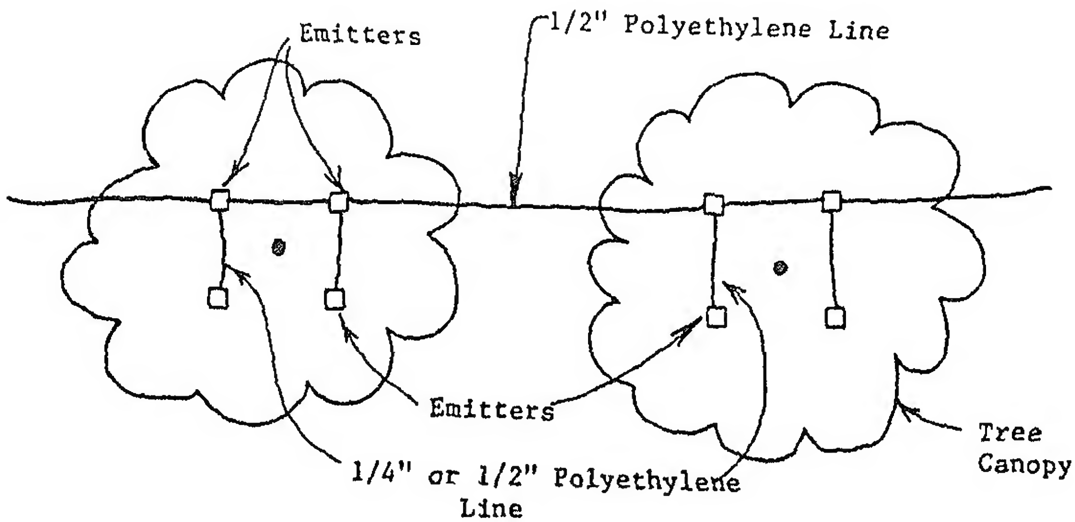
(1) Duration of application. The cheapest system that may be designed is one with the duration of application, as long as possible, keeping the flow rates throughout the system low, thus reducing pipe sizes. The choice of duration for application will be influenced by the overall irrigation schedule and by a factor of safety which should be incorporated in the design. Application time must be sufficient to replace the water that has been consumed since the previous irrigation. It can be up to 24 hours, however, it should not be continuous and if more than 15 hours are required, more emitters should be used. Ponding or runoff may be avoided by intermittent operation of the system.

(2) Number of emitters. Trickle irrigation of trees or shrubs requires a decision to be made about what percentage of roots require watering. In general, 40 percent of the area under the tree's drip line (mature size) will require moisture. A test may need to be run on the site to determine the lateral movement of water. Generally, the lateral movement (as a radius) for soils is as follows: coarse soils, 2-3 feet; medium, 4-5 feet; and fine soils, 6-8 feet. The rate of lateral movement in fine soils is so slow that emitter spacing should be limited to 4-5 feet. The emitters should be spaced equidistant around the tree and should be located 1/3 of the distance from the trunk to the drip line. See Figure C0685.25.

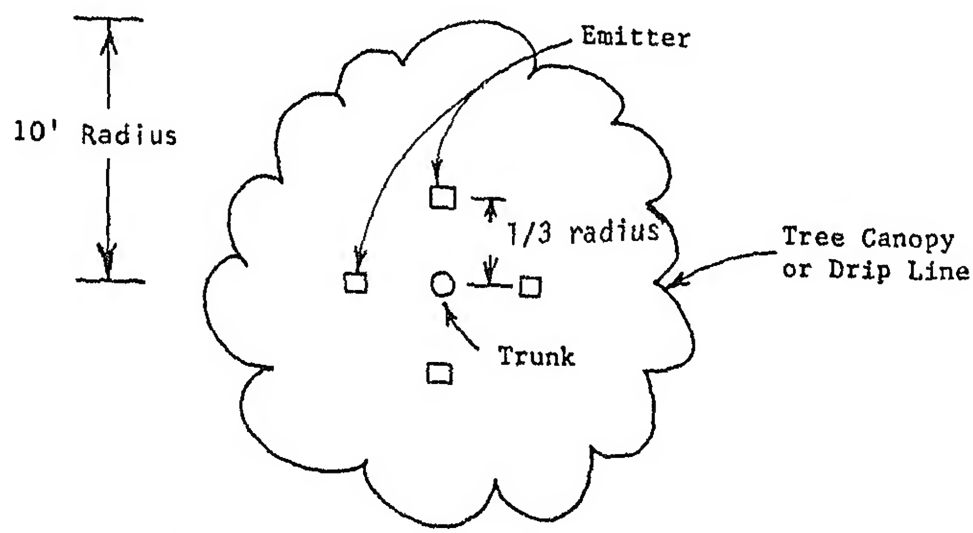
(3) Discharge per emitter. Emitters are mechanical outlets designed to operate at low pressure (5 to 25 psi) and to provide 1/2 to 3 gallons per hour (gph). One, one and one-half, and two gallons per hour capacity are most commonly used. Outlets in the range of one-half to one gallon per minute (gpm) capacity, are classified as bubblers. Emitters that discharge to the atmosphere above ground are classified as spray and operate up to 0.5 gpm. Companies providing mechanical outlets will furnish performance curves that show gallons per hour (gph) or gallons per minute (gpm) flow rates vs. pressure for each size of mechanical outlet to be used as shown on Figure C0685.26. The recommended flow rate is +/- 15 percent of the average flow rate.

C0685.44(b)(4)

(4) Additional components. The selection of emitter discharge and number allows the sizing of the laterals, mainlines, and feeder lines. Generally, the laterals, submain, and main lines are made from PVC while the feeder lines are polyethylene (PE) materials.



Emitter Location



Place emitters 1/3's of the distance from the tree trunk to the edge of the mature tree canopy; i.e., 10' radius x 1/3's = 3' ±

Figure C0685.25 Typical Emitter Installation and Location

C0685.44(b)(4)

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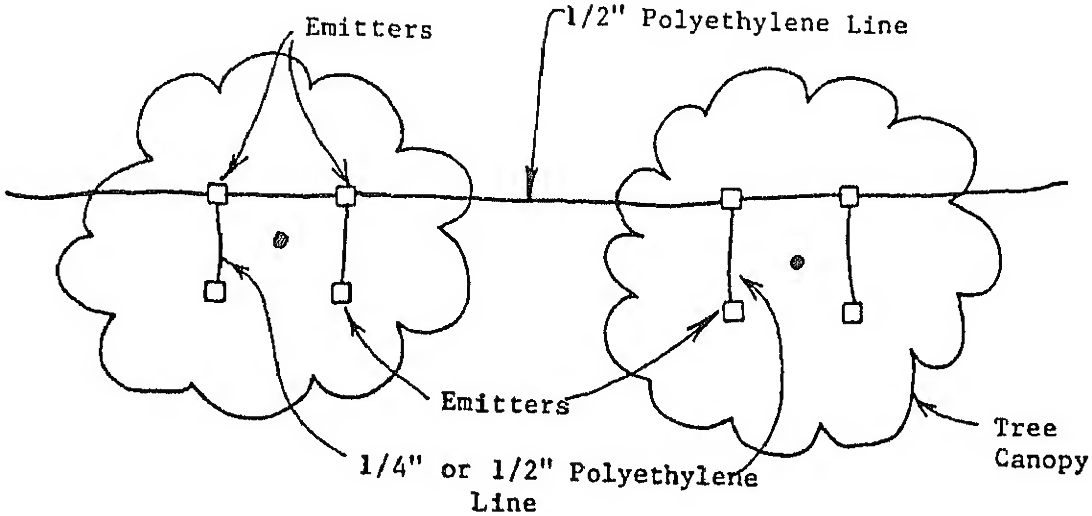
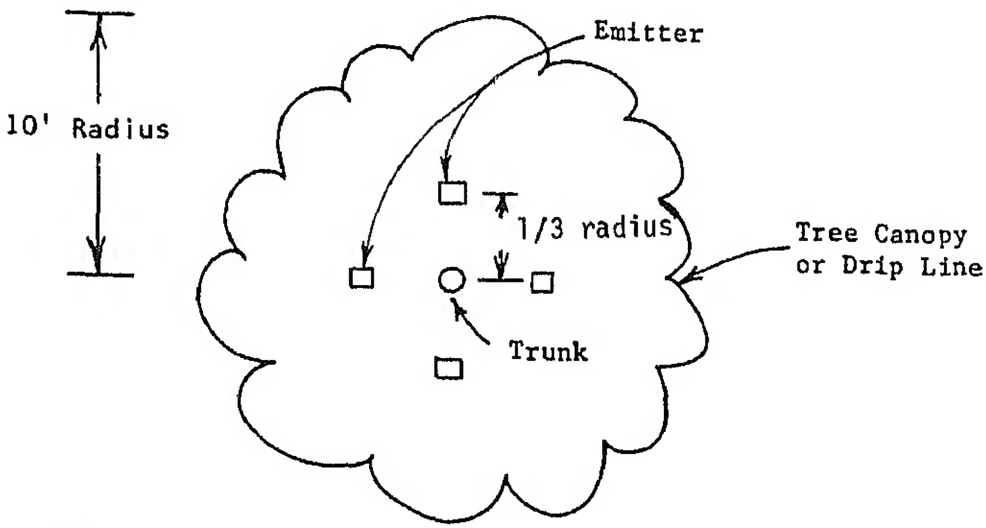


Emitter Location



Place emitters 1/3's of the distance from the tree trunk to the edge of the mature tree canopy; i.e., 10' radius x 1/3's = 3' ±

Figure C0685.25 Typical Emitter Installation and Location

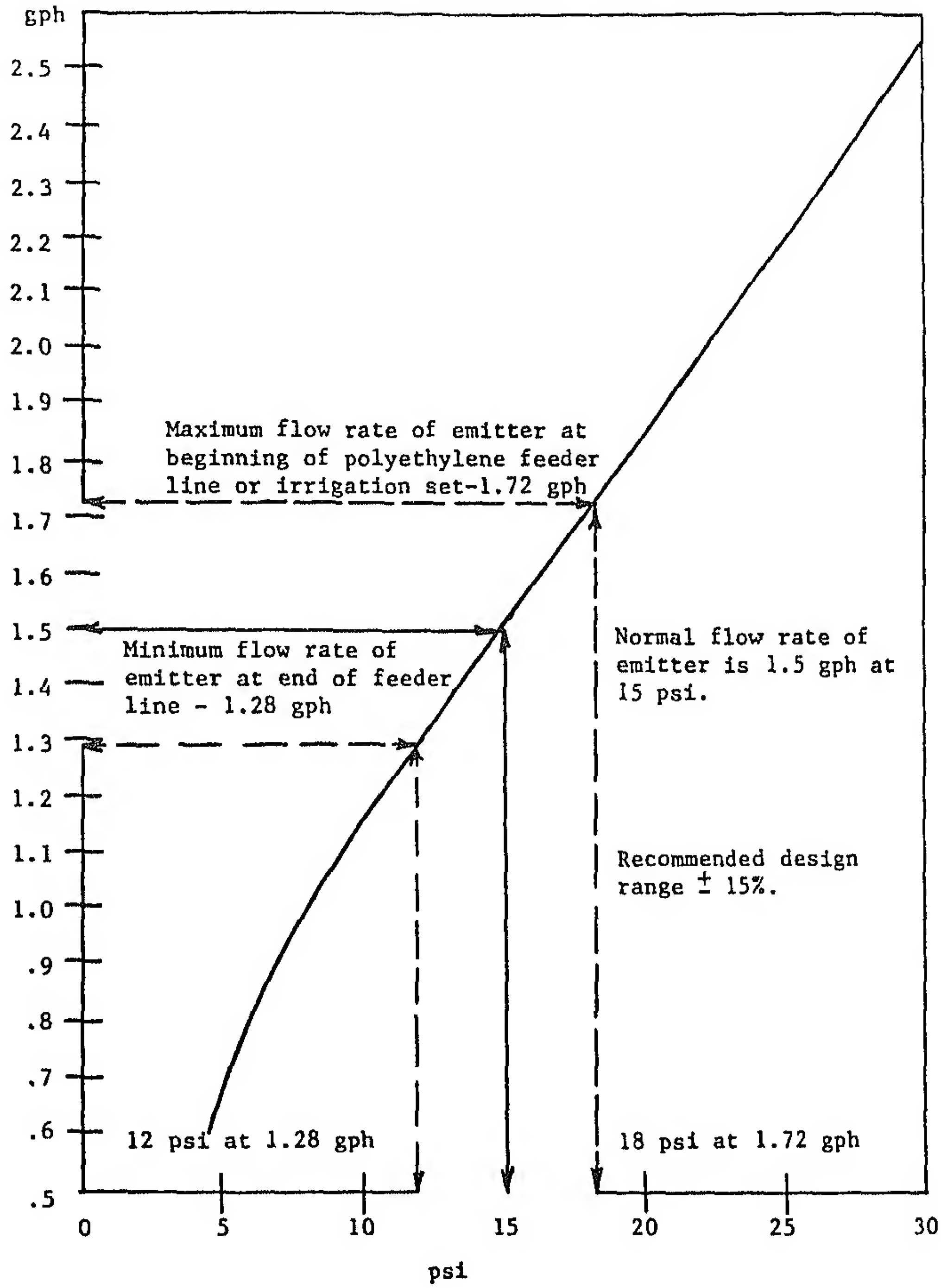


Figure C0685.26 Typical Emitter Performance Curve for 1.5 gph Emitter

CO685.44(c)

(c) In addition, one must determine the need for filters, pumps, settling basins, fertilizer injectors, chlorinators or acid injectors, and lastly, tensiometers or other soil moisture checks. Time clocks may be desired for automatically starting or ending and for irrigation sequencing. Not all systems will require all of this equipment.

CO685.45 Design criteria.

(a) Basic information needed.

(1) Topographic map including property dimensions and elevations.

(2) Tree or shrub spacing, row spacing, and direction of rows.

(3) Future expansion plans of the grower.

(4) Water, source, quality and quantity, and elevation or pressure.

(5) Legal - will irrigation company deliver a trickle flow or will storage be needed?

(6) Soils.

(b) System design.

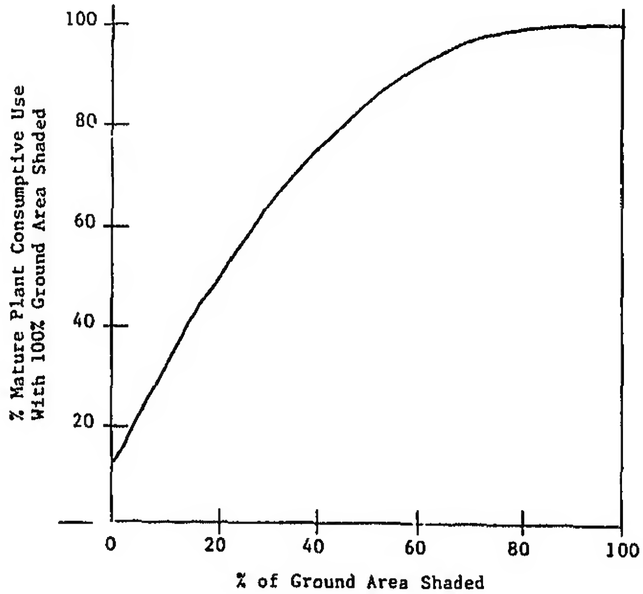
Net depth of application - $F_n = 1.604 \frac{QNTE}{Af}$

Where: F_n = net application depth in inches per day.

Q = discharge rate in gallons per hour per emitter per foot of tubing.
N = number of outlets, emitters, or total of footage of tubing.
T = hours of operation per day. Do not exceed 18 hours per day with 15 hours generally suggested as the upper limit.
A = square feet of field area served by N (number of emitters or total footage of tubing).
E = field application efficiency expressed as a decimal, 75 to 90% efficiency may be used.
f = % of total area to be wetted as a decimal.

1.604 = Units conversion constant.

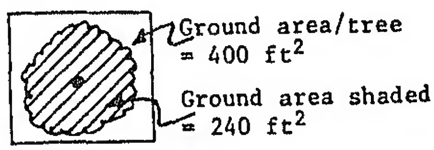
Figure C0685.27 Consumptive Use Estimate for Immature Deciduous Plants Without Cover



(c) Example Problem Estimate consumptive (ET) use of an immature peach tree

(i) <u>Given</u>: (1) Mature peach tree consumptive use is 7.5 inches for the month,

(2) Plan view of orchard:



(ii) <u>Solution</u>: From (2) above, percent of ground area shaded (PGAS):

$$PGAS = \frac{\text{Area shaded}}{\text{Area/tree}} \times 100$$

$$= \frac{240}{400} \times 100$$

$$= 60\%$$

From figure C0685.27, the correction factor for percent of mature plant consumptive use is 92%

$$\text{EST ET}_{(\text{immature})} = \text{ET}_{(\text{mature})} \times 0.92_{(\text{correction})}$$

$$= 7.5 \times .92 = 6.9 \text{ inches.}$$

CO685.46 Design procedure and example.

(a) Typical simplified drip irrigation systems design for an orchard. NEH, Section 15, Chapter 7, Trickle Irrigation, provides detailed design procedures.

(1) Given: 40-acre apple orchard

100 trees to the acre spaced at 20' X 20'

Soils are medium textured

Topography is flat

Water use is 0.3 inch per day.

The trees will be allowed to form a continuous hedge in one direction with a 6-foot lane left open in the other direction for access reasons.

(2) Emitter design (using table CO685.78)

(i) Number need - This is dependent on the size of the tree and the soil type. The tree spacing is 20' x 20' with a 6' lane left open. The area expected to be covered by the tree is therefore 20' x 14' = 280 sq. ft. The rule of thumb is that 40 percent of this area must be covered by water from emitters to keep an adequate root system alive:

280 sq. ft. x 40% = 112 sq. ft. needed

(ii) The soils are medium textured so the expected lateral movement of water is 4-5 feet. Four feet will be used for this example. Four feet is the radius of the circle so an 8-foot diameter circle will be covered by water for each emitter used. Each emitter will then cover $3.14(8)^2/4$ = 50.2 sq. ft. of area. An area of 112 sq. ft. is needed. The number of emitters needed is 112/50.2 = 2+ emitters. Use 3 emitters per tree.

(iii) Size of emitters in gallons per hour. From Table CO685.78 determine the net gallons of water needed per tree per day.

(a) Tree spacing = 20' x 20' = 400 sq. ft. per tree. The area covered by the tree is 280 sq. ft. as shown in the calculation above. Percent of the area covered is 280/400 = 0.7 or 70% cover.

(b) Using 0.3 in. water per day and interpolating between the 100 percent cover and the 50 percent cover for 100 trees per acre in the table, we need 57 gallons peak net water use per tree per day.

(c) Water is to be applied a maximum of 15 hours daily to allow for catch-up time in the event of system failures. Net flow rate required at each tree is:

$$\frac{57 \text{ gal./day/tree}}{15 \text{ hrs/day}} = 3.8 \text{ gph/tree}$$

If the delivery is 90 percent efficient, then gross flow rate to each tree is:

$$\frac{3.8}{0.90} = 4.2 \text{ gph/tree}$$

With three emitters per tree the capacity of each emitter is

(4.2)/3 = 1.4 gph/emitter.

(d) Since emitters come in 1.0 and 1.5 gph sizes select the 1.5 gph emitter. This will supply 1.5 x 3 = 4.5 gph per tree. Then 63 gallons per tree gross (57/.90 eff.) per day divided by 4.5 gallons per tree per hour = 14 hours maximum operating time needed per day in peak consumptive use time. A longer time would be specified if salts are a problem.

(iv) Type of emitter - Since the orchard is flat, pressure compensation emitters are not needed. Any 1.5 gph emitter manufactured by reputable irrigation company will do the job. Pressure compensating emitters need to be considered when fall exceeds ± 1 percent.

(3) Polyethylene (PE) feeder line design.

(i) Assume a pressure regulator is set on the riser from the mainline next to the feeder line. Generally ± 15 percent of the flow rate is absorbed between the first emitter downstream from the pressure regulator (Tree C) and the last emitter on the line when there is no elevation difference.

1.5 gph + 15% = 1.5 + .22 = 1.72 gph max flow rate

1.5 gph - 15% = 1.5 - .22 = 1.28 gph min flow rate

C0685.46(a)(3)(ii)

(ii) From Figure C0685.26, emitter performance curve, we find pressure of 18 psi needed to get 1.72 gph, and a pressure of 12 psi needed to get 1.28 gph; therefore, 18 - 12 = 6 psi pressure loss available in the polyethylene feeder line--the pressure regulator on the riser at the main line should be set at 18 psi. From Table C0685.79, polyethylene friction table, the number of trees that can be placed on one feeder line can now be determined. The one-half inch polyethylene line is most often used. It is kept in stock by most drip irrigation companies.

(iii) The flow rate is 4.5 gph per tree. The first friction loss (J) given is for 5 gph. Friction losses for flows up to 5 gph can be assumed to be negligible. Tree spacing is 20 feet. The polyethylene line length is 20 feet + 5 percent slack so the emitters won't move. The length of polyethylene between each tree is then 20 feet + 5 percent of 20 = 21 ft. The friction losses in the table are for 100 feet of polyethylene. Multiply Figures (J) in the table by 21 divided by 100 to get the pressure loss between trees. For 18 gph, the friction loss factor (J) is .22 ft. loss for the 21 feet of PE between the 4th and 5th trees. (4 x 4.5 gph per tree = 18 gph) continue this procedure for 22.5 gph (4.5 gph per tree x 5 trees) etc., until the 6 psi maximum accumulated loss is reached by adding these "between tree" losses together; that would then be the total number of trees allowed per one-half inch polyethylene feeder line.

(iv) A much quicker method of determining total accumulated lateral loss is to enter table C0685.79 with total lateral beginning flow and obtain friction loss factor (J) in ft/100 ft. Multiply this factor (J) times total lateral length (including contraction-expansion allowance), times multiple outlet factor (F) (Table C0685.72) to obtain total lateral friction loss in feet.

(3) Size the main lines--the buried plastic high-pressure lines.

(i) Layout the system to use the longest polyethylene feeder lines practical. This will give the shortest length of main line and the least number of fittings. This will reduce material and installation costs. Standard friction tables are contained in Subpart F - Tables. Other tables are available in the SCS Engineering Field Manual and from the manufacturers of plastic pipe. These tables can be used to determine friction losses in the main lines and fittings.

(4) Determine the pump size needed.

(i) 100 trees per acre times 40 acres = 4000 trees. 4000 trees x 3 emitters per tree = 12,000 emitters. 12,000 emitters @ 1.5 gph per emitter = 18,000 gph. 18,000 gph/60 = 300 gpm pump capacity needed to operate the entire 40 acre orchard at one time for 14 hours during the peak use period. The head to pump against is determined as follows: 18 psi is needed at the pressure regulator on the polyethylene feeder line. Add friction losses in the main line and fittings to this. Add 5-10 psi for losses through the filters according to the manufacturer's literature. Also, add losses through the flow meter, gate valves, etc...

(5) Determine the filter size needed.

(i) The manufacturer's data should be used for this step. The quality of the water in this example dictates that a sand filter will be backed up by a screen filter. The manufacturer's literature suggests a 20 gpm capacity per sq. ft. of sand filter. 300 gpm/20gpm/ft^2 = 15 sq. ft. filter area needed. Two 36-inch diameter tanks will be used. Consult the manufacturer`s recommendations for the screen filter.

(6) Design all other equipment needed in accordance with good engineering practice and the manufacturer's literature. Include as needed: a chlorinator, check valves, pressure relief valves, combination air-vacuum valves, fertilizer injectors, flow meters, non-vibratory coupling and gate valves.

CO685.47 Layout

(a) Polyethylene or similar material is used for the feeder lines. The size varies from smaller than 3/8" to 1" in diameter. The most common size used is the 1/2 inch, which is 15 millimeters or 0.580-inch inside diameter. Care must be taken to specify that this material be recognized drip line polyethylene tubing. Not all polyethylene will withstand the variation in temperature required for above-ground installation and may deteriorate rapidly.

(b) Five-percent slack is left in the feeder line so temperature variations will not pull the mechanical outlets away from their initial resting place. In a sprinkler conversion, tree roots will die out in unwatered areas and develop more strongly in the area of the mechanical outlet. Later moving of this outlet may kill the tree.

C0685.47(c)

(c) When laid above ground, the feeder lines are placed so that equipment will not need to run over the lines. Picking of fruit will need to be done so boxes or other equipment will not be dragged across feeder lines.

(d) The feeder lines are connected to buried main lines and laterals through risers, flexible PVC, or other acceptable means. Pressure regulators may be installed on each riser to reduce pressure from the main line to the feeder line. This allows the full ± 15 percent flow rate pressure loss to be absorbed in the feeder line. An alternate method of design puts a pressure regulator in the main line just upstream from several feeder lines. In this case, the pressure loss is absorbed in the main line plus the feeder lines. The advantage of a pressure regulator on each feeder line is the ease of design and close adherence to allowed pressure loss. The advantage of the other system is the smaller number of pressure regulators required which relates to cost and durability of equipment.

C0685.48 Component criteria and considerations

(a) Laterals and main lines: Normally constructed of polyvinyl chloride (PVC) they must be installed in accordance with good engineering practice. Gate valves are used to isolate sections of the system in case shutdowns are needed to repair breaks or perform other maintenance.

(b) Filters, separators and screens: These devices are sometimes used in combinations. For instance, a sand separator may be used in very dirty water, backed up by a screen. Sometimes a screen is used downstream from a sand filter in case of failure of the sand filter. Five to 15 psi pressure loss can be expected across filters.

(1) <u>Sand separators.</u> Are generally associated with the removal of sand particles where an exceptionally dirty water supply is used. They can remove particulate matter (200 mesh) when the material is heavier than water. They are not effective in removing algae, trash, and silt that tend to plug system outlets.

(2) <u>Screen filters.</u> 20-mesh to 200-mesh screen assemblies are available to remove sediment and other foreign material. Industry has automatic self flushing and cleaning devices available. These screen assemblies will remove sand, debris, organic material, some minerals, and some silt. They are not effective in removing algae spores.

C0685.48(f)

(3) Sand filter. Looks much like a swimming pool sand filter. Normal design provides 1 sq. ft. of filter area to 20 gpm system capacity. For dirty water, this may go to 1 sq. ft. to 15 gpm. Sand filters can be automated to self clean when there is a 5 to 10 psi differential across the filter. At least two filters in series are required to allow for flushing to alternate between filters and assure that water delivery is still being filtered. The total number of filters is regulated by system flow requirements and the size of filters available.

(c) Pumps: The vertical turbine or centrifugal are most commonly used. The centrifugal has the advantage of lower initial cost and easier installation. The vertical turbine pump has longer life and a lower operating cost. The vertical turbine can operate in a wider range of pressures and water supply without injuring the pump. It is recommended that the system be designed for continuous operation during peak use. This avoids extra demand changes that would exist if it was designed for only 12 to 18 hours of operation per day. Automatic pump controls should be used to protect the pump from hazards, such as electricity cutoff (for electric motor drive) and cutoff of water supply.

(d) Settling basin: Drip systems are often installed where traditional surface irrigation systems have been used. It is sometimes necessary to install a settling basin to remove trash, debris, and an especially heavy silt load. This basin can also be used as a regulating reservoir to insure a good match between incoming water supplies and the pump. A trash screen may suffice instead of the settling basin.

(e) Fertilizer injectors or pumps: There are several types on the market including flow meter, metering pump, and others. These should all be installed upstream of the filters so unfiltered fertilizer will not plug the feeder lines and emitters.

(f) Chlorinator and acid injector: These are optional depending on the quality of water used. Research data still in the experimental stage indicates that where needed, chlorine injected at 1 ppm residual on a continuous basis and intermittent applications of 10 ppm residual chlorine for 20 minutes daily lowered plugging counts for an 8-day period. Acid solutions are used to lower pH to the neutral range to make the chlorine more effective. This is done because acid is relatively cheap while chlorine is expensive. Acid has also been used successfully to reclaim flush-type emitters that were plugged with a slime matrix and suspended material. This acid was also used to reclaim emitters blocked with carbonate residue.

CO685.48(g)

(g) Tensiometers or other soil moisture check: Tensiometers, neutron probes, and soil moisture blocks should be used to check the soil moisture condition. Normally, a check is made at a depth where the main root concentration is found. A second soil moisture check is made below the main root zone. When water is reaching this area, the irrigation should be stopped. For tree crops, tensiometers could be placed at 18- to 36-inch depth.

SUBPART F - TABLES

C0685.60

Table C0685.60 Intake Opportunity Time in Minutes for Net Depth of Application and Intake Family

Intake Family Number	Net Depth of Application (Fn) inches 1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0
0.1	169	374	628	923	1254	2012	2884	3855
0.3	62	129	208	296	392	604	840	1097
0.5	38	75	118	166	217	328	449	579
1.0	20	38	59	82	106	158	214	273
1.5	14	26	40	55	72	106	142	181
2.0	11	20	31	42	54	80	107	136
3.0	7	14	21	29	37	54	72	91
4.0	6	11	16	22	28	41	55	69

Table C0685.61 Coefficient of Roughness Values (n)

Crop	Stage of Growth or Condition	Design 'n'
None	smooth bare soil	0.04
Small Grain	drill row parallel to strip	0.10
Alfalfa	. . . .	0.15
Small Grain	broadcast planted	0.15
Small Grain	drilled across the border strip	0.25
Dense sodded Crops	broadcast planted	0.25

Table C0685.62 Recommended Maximum Design Efficiency for Level Border Irrigation

Fn (in.)	Intake Family 0.1	0.3	0.5	1.0	1.5	2.0	3.0
1.0	70	70	60	50	--	--	--
1.5	75	75	70	60	50	50	50
2.0	75	75	70	60	50	50	50
2.5	80	80	75	70	60	60	50
3.0	80	80	75	70	60	60	50
3.5	85	85	80	75	70	70	60
4.0	85	85	80	75	70	70	60
5.0	90	90	85	80	75	70	60

C0685.63

Table C0685.63 Recommended Design Efficiency for Graded Border Irrigation

Irrigation slope s_o	Intake family																														
	0.3				0.5					1.0					1.5					2.0					3.0				4.0			
	Net depth of application (F_n) in inches																														
	1	2	3	4	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	1	2	3	4
Feet per foot	Percent																														
0.0005	65	65	70	70	65	65	70	70	70	75	75	80	80	80	75	75	80	80	80	75	75	80	80	80	65	70	70	70	65	70	70	70
.0010	60	60	65	65	65	65	70	70	70	70	70	75	75	75	75	75	80	80	80	75	75	80	80	80	65	70	70	70	65	70	70	70
.0020	60	60	55	50	65	65	70	70	70	65	65	70	70	70	70	70	75	75	75	70	70	75	75	75	65	70	70	70	65	70	70	70
.0030	55	55	50		60	60	65	65	65	65	65	70	70	70	65	65	70	70	70	65	65	70	70	70	65	70	70	70	65	70	70	70
.0040	55	50			60	60	65	60	55	60	60	65	65	65	65	65	70	70	70	65	65	70	70	70	65	70	70	70	60	65	65	65
.0050	50				60	60	60	55	50	60	60	65	65	65	65	65	70	70	70	65	65	70	70	70	65	70	70	70	60	65	65	65
.0075					55	55	50			60	60	65	65	65	60	60	65	65	65	65	65	70	70	70	65	70	70	70	60	65	65	65
.0100					55	55				60	60	65	65	65	60	60	65	65	65	60	60	65	65	65	60	65	65	65	60	65	65	65
.0150					55					55	55	60	60	60	60	60	65	65	65	60	60	65	65	65	60	65	65	65	60	65	65	65
.0200					50					55	55	60	55	50	60	60	65	65	65	60	60	65	65	65	60	65	65	65	60	65	65	65
.0250										55	55	55	50		60	60	65	65	65	60	60	65	65	65	60	65	65	65		60	60	60
.0300										55	55	50			55	55	60	60	60	55	55	60	60	60	55	60	60	60		60	60	60
.0400										50	50				55	55	60	60	55		55	60	60	60		60	60	60				
.0500															55	55	60	55	50		55	60	60	60								
.0600															50	50	55	50				55	55	55								

Table C0685.64 Stream Sizes for Border Irrigation

Slope	Crops Nonsod	Sod
Feet per feet	cfs/ft of width	
0.0005	0.567	1.113
.0010	.337	.674
.0020	.200	.400
.0030	.148	.296
.0040	.119	.238
.0050	.101	.202
.0075	.075	.149
.0100	.060	.120
.0150	.044	.089
.0200	.036	.072
.0250	.030	.060
.0300	.026	.053
.0400	.021	.042
.0500	.018	.036
.0600	.016	.031

Table C0685.65 Minimum Value of Q_u/L to Assure Complete Border Width Coverage

Slope	n = 0.04	n = 0.15	n = 0.25
Feet per foot		cfs/ft of width/ft of length	
0.0005	0.00003578	0.00000954	0.00000572
.0010	.00005060	.00001349	.00000810
.0020	.00007155	.00001908	.00001145
.0030	.00008763	.00002337	.00001402
.0040	.00010120	.00002699	.00001619
.0050	.00011313	.00003017	.00001810
.0075	.00013855	.00003695	.00002217
.0100	.00016000	.00004267	.00002560
.0151	.00019600	.00005227	.00003136
.0200	.00022625	.00006033	.00003620
.0250	.00025295	.00006745	.00004047
.0300	.00027713	.00007390	.00004434
.0400	.00032000	.00008533	.00005120
.0500	.00035775	.00009540	.00005724
.0600	.00039185	.00010449	.00006270

C0685.66

Table C0685.66 Maximum Slopes for Graded Border Irrigation as Limited by Minimum Depth of Flow Requirements or by a Minimum Border Length of 100 Feet

Intake Family	Appl. Depth	n = 0.04 Efficiency - percent						n = 0.15 Efficiency - percent						n = 0.25 Efficiency - percent					
		50	55	60	65	70	75	50	55	60	65	70	75	50	55	60	65	70	75
	in.	Feet per foot						Feet per foot						Feet per foot					
0.3	1	.001*	.001*	.001*	.001*			.011*	.009*	.008*	.006*			.030*	.025*	.021*	.018*		
	2	#	#	#	#			.004*	.003*	.003*	.002*			.011*	.009*	.008*	.006*		
	3	#	#	#	#	#		.003*	.002*	.002*	.002*	.001*		.007*	.006*	.005*	.004*	.004*	
	4	#	#	#	#	#		.002*	.002*	.001*	.001*	.001*		.005*	.004*	.004*	.003*	.003*	
0.5	1	.002*	.002*	.001*	.001*			.030*	.025*	.021*	.018*			.083*	.069*	.058*	.049*		
	2	.001*	.001*	.001*	.001*			.012*	.010*	.008*	.007*			.033*	.027*	.023*	.020*		
	3	.001*	.001*	#	#	#		.008*	.007*	.006*	.005*	.004*		.023*	.019*	.016*	.013*	.011*	
	4	#	#	#	#	#		.006*	.005*	.004*	.004*	.003*		.018*	.014*	.012*	.010*	.009*	
	5	#	#	#	#	#		.005*	.004*	.004*	.003*	.003*		.015*	.012*	.010*	.009*	.007*	
1.0	1	.008*	.006*	.005*	.005*	.004*	.003*	.069	.078	.077*	.065*	.056*	.049*	.069	.078	.087	.097	.107	.118
	2	.003*	.003*	.002*	.002*	.002*	.002*	.048*	.040*	.034*	.029*	.025*	.022*	.119	.111*	.093*	.079*	.069*	.060*
	3	.002*	.002*	.002*	.001*	.001*	.001*	.034*	.028*	.024*	.020*	.017*	.015*	.094*	.078*	.065*	.056*	.048*	.042*
	4	.002*	.002*	.001*	.001*	.001*	.001*	.027*	.022*	.019*	.016*	.014*	.012*	.075*	.062*	.052*	.045*	.039*	.034*
	5	.002*	.001*	.001*	.001*	.001*	.001*	.023*	.019*	.016*	.014*	.012*	.010*	.064*	.053*	.045*	.038*	.033*	.029*
1.5	1	.016*	.013*	.011*	.010*	.008*	.007*	.042	.048	.054	.060	.066	.072	.042	.048	.054	.060	.066	.072
	2	.007*	.006*	.005*	.004*	.004*	.003*	.071	.081	.072*	.062*	.053*	.046*	.071	.081	.091	.101	.112	.123
	3	.005*	.004*	.004*	.003*	.003*	.002*	.074*	.062*	.052*	.044*	.038*	.033*	.089	.101	.114	.122*	.105*	.092*
	4	.004*	.004*	.003*	.003*	.002*	.002*	.060*	.050*	.042*	.036*	.031*	.027*	.103	.116	.116*	.099*	.086*	.075*
	5	.004*	.003*	.003*	.002*	.002*	.002*	.052*	.043*	.036*	.031*	.026*	.023*	.113	.119*	.100*	.085*	.073*	.064*
2.0	1	.027*	.023*	.019*	.016*	.014*	.012*	.030	.034	.038	.042	.047	.051	.030	.034	.038	.042	.047	.051
	2	.013*	.011*	.009*	.008*	.006*	.006*	.050	.056	.063	.070	.078	.080*	.050	.056	.063	.070	.078	.085
	3	.009*	.008*	.006*	.005*	.005*	.004*	.062	.070	.079	.077*	.066*	.058*	.062	.070	.079	.087	.096	.106
	4	.008*	.006*	.005*	.004*	.004*	.003*	.070	.080	.074*	.063*	.055*	.047*	.070	.080	.089	.100	.110	.120
	5	.007*	.005*	.005*	.004*	.003*	.003*	.077	.077*	.064*	.055*	.047*	.041*	.077	.087	.098	.109	.120	.114*
3.0	1	.018	.021	.023	.026			.018	.021	.023	.026			.018	.021	.023	.026		
	2	.027*	.023*	.019*	.016*			.030	.034	.038	.042			.030	.034	.038	.042		
	3	.020*	.017*	.014*	.012*	.010*		.037	.042	.047	.052	.058		.037	.042	.047	.052	.058	
	4	.017*	.014*	.012*	.010*	.008*		.042	.047	.053	.059	.065		.042	.047	.053	.059	.065	
	5	.014*	.012*	.010*	.009*	.007*		.046	.052	.058	.065	.071		.046	.052	.058	.065	.071	
4.0	1	.013	.015	.016	.018			.013	.015	.016	.018			.013	.015	.016	.018		
	2	.021	.024	.027	.028*			.021	.024	.027	.030			.021	.024	.027	.030		
	3	.026	.028*	.024*	.020*	.018*		.026	.029	.033	.036	.040		.026	.029	.033	.036	.040	
	4	.029*	.024*	.020*	.017*	.015*		.029	.033	.037	.041	.045		.029	.033	.037	.041	.045	
	5	.025*	.021*	.017*	.015*	.013*		.032	.036	.040	.045	.050		.032	.036	.040	.045	.050	

Not adapted for graded borders

* Slope limited by depth requirements

Table C0685.67 Precipitation Rates (in/hr) for Various Sprinkler Spacings and Discharge Rates

Spacing (feet)	Gallons per Minute from each Sprinkler																	
	1	2	3	4	5	6	8	10	12	15	18	20	25	30	35	40	45	50
20 X 20	0.24	0.48	0.72	0.96	1.20	1.44	1.92											
20 X 30	0.16	0.32	0.48	0.64	0.80	0.96	1.28	1.60	1.93									
20 X 40	0.12	0.24	0.36	0.48	0.60	0.72	0.96	1.20	1.45	1.81	2.17							
20 X 50	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.20	1.50	1.80	2.00						
20 X 60	0.08	0.16	0.24	0.32	0.40	0.48	0.64	0.80	0.96	1.20	1.44	1.60	2.00					
25 X 25	0.15	0.30	0.46	0.61	0.77	0.92	1.23	1.54	1.85	2.31								
30 X 30	0.11	0.21	0.32	0.43	0.54	0.64	0.86	1.07	1.28	1.61	1.93	2.14						
30 X 40		0.16	0.24	0.32	0.40	0.48	0.64	0.80	0.96	1.20	1.45	1.61	2.01	2.40				
30 X 50		0.13	0.19	0.25	0.32	0.38	0.51	0.64	0.76	0.96	1.15	1.28	1.60	1.92				
30 X 60		0.11	0.16	0.21	0.27	0.32	0.43	0.53	0.64	0.80	0.96	1.07	1.54	1.61	1.87	2.14		
40 X 40		0.12	0.18	0.24	0.30	0.36	0.48	0.60	0.72	0.90	1.08	1.20	1.50	1.80	2.10	2.40		
40 X 50		0.10	0.14	0.19	0.24	0.29	0.38	0.48	0.58	0.72	0.86	0.96	1.20	1.44	1.68	1.92	2.16	
40 X 60			0.12	0.16	0.20	0.24	0.32	0.40	0.48	0.60	0.72	0.80	1.00	1.20	1.40	1.60	1.80	2.00
40 X 80			0.09	0.12	0.15	0.18	0.24	0.30	0.36	0.45	0.54	0.60	0.75	0.90	1.05	1.20	1.35	1.50
50 X 50			0.12	0.15	0.19	0.23	0.31	0.39	0.46	0.58	0.69	0.77	0.96	1.15	1.35	1.54	1.73	1.92
50 X 60			0.10	0.13	0.16	0.19	0.26	0.32	0.39	0.48	0.58	0.64	0.80	0.96	1.12	1.28	1.44	1.60
50 X 70				0.11	0.14	0.17	0.22	0.28	0.33	0.41	0.49	0.55	0.69	0.82	0.96	1.10	1.24	1.37
60 X 60				0.11	0.13	0.16	0.21	0.27	0.32	0.40	0.48	0.53	0.67	0.80	0.93	1.07	1.20	1.34
60 X 70					0.11	0.14	0.18	0.23	0.27	0.34	0.41	0.46	0.57	0.69	0.80	0.92	1.03	1.15
60 X 80					0.10	0.12	0.16	0.20	0.24	0.30	0.36	0.40	0.50	0.60	0.70	0.80	0.90	1.00
70 X 70					0.10	0.12	0.16	0.20	0.24	0.29	0.35	0.39	0.49	0.59	0.69	0.79	0.88	0.98
70 X 80						0.10	0.14	0.17	0.21	0.26	0.31	0.34	0.43	0.52	0.60	0.69	0.77	0.86
70 X 90							0.12	0.15	0.18	0.23	0.28	0.30	0.37	0.46	0.53	0.61	0.69	0.76
80 X 80							0.12	0.15	0.18	0.23	0.27	0.30	0.38	0.45	0.53	0.60	0.68	0.75
80 X 90							0.11	0.13	0.16	0.20	0.24	0.27	0.33	0.40	0.47	0.53	0.60	0.67
80 X 100							0.10	0.12	0.14	0.18	0.22	0.24	0.30	0.36	0.42	0.48	0.54	0.60
100 X 100								0.10	0.12	0.14	0.17	0.19	0.24	0.29	0.34	0.39	0.43	0.48

C0685.68

Table C0685.68 Maximum Sprinkler System Capacity Requirements for Various Operating Efficiencies and Hours-Per-Day of Operation

Peak Daily Consumptive Use Rate (in/day)	System Capacity Requirements (gpm/acre*) 60% Efficiency Hours/day Operation 21	22	23	24	65% Efficiency Hours/day Operation 21	22	23	24	70% Efficiency Hours/day Operation 21	22	23	24
0.12	4.31	4.12	3.94	3.78	3.98	3.80	3.64	3.48	3.70	3.53	3.38	3.24
0.14	5.03	4.80	4.60	4.40	4.65	4.43	4.24	4.07	4.31	4.12	3.94	3.78
0.16	5.75	5.49	5.25	5.03	5.31	5.07	4.85	4.65	4.93	4.71	4.50	4.31
0.18	6.47	6.18	5.91	5.66	5.97	5.70	5.45	5.23	5 55	5.29	5.06	4.85
0.20	7.19	6.86	6.57	6.29	6.64	6.34	6.06	5.81	6.16	5.88	5.63	5.39
0.22	7.91	7.55	7.22	6.92	7.30	6.97	6.67	6.39	6.78	6.47	6.19	5.93
0.24	8.63	8.24	7.88	7.55	7.96	7.60	7.27	6.97	7.40	7.06	6.75	6.47
0.26	9.35	8.92	8.53	8.18	8.63	8.24	7.88	7.55	8.01	7.65	7.32	7.01
0.28	10.07	9.61	9.19	8.81	9.29	8.87	8.48	8.13	8.63	8.24	7.88	7.55
0.30	10.79	10.30	9.85	9.44	9.96	9.50	9.09	8.71	9.24	8.82	8.44	8.09
0.32	11.50	10.98	10.50	10.07	10.62	10.14	9.70	9.29	9.86	9.41	9.00	8.63
0.34	12.22	11.67	11.16	10.70	11.28	10.77	10.30	9.87	10.48	10.00	9.57	9.17
0.36	12.94	12.35	11.82	11.33	11.95	11.40	10.91	10.45	11.09	10 59	10.13	9.71
0.38	13.66	13.04	12.47	11.95	12.61	12.04	11.51	11.03	11.71	11 18	10.69	10.25
0.40	14.38	13.73	13.13	12.58	13.27	12.67	12.12	11.62	12.33	11.77	11.25	10.79
0.42	15.10	14.41	13.79	13.21	13.94	13.30	12.73	12.20	12.94	12 35	11.82	11 33
0.44	15.82	15.10	14.44	13.84	14.60	13.94	13.33	12.78	13.56	12.94	12.38	11.86
0.46	16.54	15.79	15.10	14.47	15.27	14.57	13.94	13.36	14.18	13.53	12.94	12.40
0.48	17.26	16.47	15.76	15.10	15.93	15.21	14.54	13.94	14.79	14.12	13.51	12.94
0.50	17.98	17.16	16.41	15.73	16.59	15.84	15.15	14.52	15.41	14.71	14.07	13.48

* To obtain total system requirement in gpm, multiply number of acres by value selected from table.

$$q = \frac{453 \times U}{H \times Eff.}$$

Where: q = system capacity (gpm/ac).
U = peak daily consumptive use (in/day).
H = operating time (hr/day).
Eff. = *application efficiency*

Table C0685.69 Design Field Efficiencies for Sprinkler Irrigation

Systems Requiring Scheduled Moves			
Net Irrigation Application	Sprinkler Application Rate (in/hr)		
(in)	< 0.3	0.3 - 0.5	> 0.5
<2.0	55	60	65
2.0 -2.9	60	65	70
>3.0	65	70	75

Solid Set Systems and Systems Using Continuous Moving Laterals			
Net Irrigation Application	Sprinkler Application Rate (in/hr)		
(in)	< 0.3	0.3 - 0.5	> 0.5
<1.0	60	65	70
1.0 - 1.9	65	70	75
>2.0	70	75	80

Table C0685.70 Suggested Maximum Application Rates for Average Soil, Slope, and Tilth

Soil Texture and Profile	Range of Slope 0 - 5 % (in/hr)	5 - 8 % (in/hr)	8 - 12 % (in/hr)	12 - 16 % (in/hr)
1. Coarse sandy soil to 6 ft.	2.00	1.50	1.00	0.50
2. Coarse sandy soil over more compact soils	1.50	1.00	0.75	0.40
3. Light sandy loam to 6 ft.	1.00	0.80	0.60	0.40
4. Light sandy loam over more compact soils	0.75	0.50	0.40	0.30
5. Silt loams to 6 ft.	0.50	0.40	0.30	0.20
6. Silt loams over more compact soils	0.30	0.25	0.15	0.10
7. Heavy-textured clays or clay loams	0.15	0.10	0.08	0.06

C0685.71(1)

Table C0685.71(1) A guide to recommended nozzle sizes and pressures with expected average CU values for different application rates and sprinkler spacings under low wind conditions (0 to 4 mph).

Spacing ft × ft	Sprinkler Operation	Water application rate, iph ± 0.02 iph 0.10	0.15	0.20	0.25	0.30	0.35	0.40
30 × 40	Nozzle, inch	3/32	3/32	7/64	1/8	9/64	5/32	9/64×3/32
	Pressure, psi	30	50	45	45	45	40	40
	CU, %	82	83	82	83	83	85	88
30 × 50	Nozzle, inch	3/32	7/64	1/8	9/64	5/32	11/64	11/64
	Pressure, psi	40	40	45	50	45	45	50
	CU, %	83	88	86	86	84	85	86
30 × 60	Nozzle, inch		1/8	9/64	5/32	11/64	3/16	3/16
	Pressure, psi		40	45	45	45	45	50
	CU, %		88	83	89	88	85	87
40 × 40	Nozzle, inch	7/64	1/8	9/64	1/8×3/32	5/32×3/32	5/32×3/32	5/32×1/8
	Pressure, psi	30	35	35	40	35	40	35
	CU, %	78	82	86	87	88	89	90
40 × 50	Nozzle, inch			5/32	5/32×3/32	5/32×3/32	11/64×3/32	3/16×3/32
	Pressure, psi			35	35	45	40	40
	CU, %			78	83	84	88	89
40 × 60	Nozzle, inch			5/32	11/64	3/16	13/64	7/32
	Pressure, psi			50	50	50	50	50
	CU, %			83	85	85	84	86
60 × 60	Nozzle, inch			3/16	13/64	7/32	7/32	1/4
	Pressure, psi			60	65	65	80	88
	CU, %			88	88	88	88	88

Table C0685.71(2) A guide to recommended nozzle sizes and pressures with expected average CU values for different application rates and sprinkler spacings under moderate wind conditions (4-10 mph).

Sprinkler		Water application rate, iph ± 0.02 iph						
Spacing ft × ft	Operation	0.10	0.15	0.20	0.25	0.30	0.35	0 40
30 × 40	Nozzle, inch	3/32	3/32	7/64	1/8	9/64	5/32	9/64x3/32
	Pressure, psi	30	50	45	45	45	40	40
	CU, %	82	85	85	82	83	84	85
30 × 50	Nozzle, inch	3/32	7/64	1/8	9/64	5/32	11/64	11/64
	Pressure, psi	40	40	45	50	45	45	50
	CU, %	70	75	84	84	84	87	85
30 × 60	Nozzle, inch		1/8	9/64	5/32	11/64	3/16	3/16
	Pressure, psi		40	45	45	45	45	50
	CU, %		80	84	84	84	85	86
40 × 40	Nozzle, inch	7/64	1/8	9/64	1/8x3/32	5/32x3/32	5/32x3/22	5/32x1/8
	Pressure, psi	30	35	35	40	35	40	35
	CU, %	80	83	83	83	84	87	86
40 × 50	Nozzle, inch			5/32	5/32x3/32	5/32x3/32	11/64x3/32	3/16x3/32
	Pressure, psi			35	35	45	40	40
	CU, %			76	76	76	83	84
40 × 60	Nozzle, inch			4/32	11/64	3/16	13/64	7/32
	Pressure, psi			50	50	50	50	50
	CU, %			77	81	83	84	85
60 × 60	Nozzle, inch			3/16	13/64	7/32	7/32	1/4
	Pressure, psi			60	65	65	80	68
	CU, %			80	82	83	84	84

C0685.71(3)

Table C0685.71(3) A guide to recommended nozzle sizes and pressures with expected average CU values for different application rates and sprinkler spacings under high wind conditions (10-15 mph).

		Water application rate, iph ± 0.02 iph						
		0.10	0.15	0.20	0.25	0.30	0.35	0.40
		3/32	3/32	7/64	1/8	9/64	5/32	5/32
		30	50	45	45	45	40	45
		75	80	80	84	84	85	86
			7/64	1/8	9/64	5/32	11/64	11/64
			40	45	50	45	50	55
			70	81	82	87	88	88
30 X 60	Nozzle, inch			9/64	5/32	11/64	3/16	3/16
	Pressure, psi			45	45	45	45	50
	CU, %			72	75	81	84	86
40 X 40	Nozzle, inch		1/8	9/64	5/32	11/64	11/64	3/16
	Pressure, psi		35	35	35	35	50	45
	CU, %		80	82	81	80	86	85
40 X 50	Nozzle, inch			5/32	5/32	11/64	3/16	13/64
	Pressure, psi			35	50	50	50	50
	CU, %			77	78	80	80	82
40 X 60	Nozzle, inch			5/32	11/64	3/16	13/64	7/32
	Pressure, psi			50	50	50	50	50
	CU, %			68	74	78	81	82
60 X 60	Nozzle, inch			3/16	13/64	7/32	7/32	1/4
	Pressure, psi			60	65	65	80	68
	CU, %			64	66	68	80	82

Table C0685.71(4) A guide to recommended nozzle sizes and pressures with expected average CU values for different application rates and sprinkler spacings under extreme wind conditions (15-20 mph).

Sprinkler		Water application rate, iph ± 0.02 iph						
Spacing ft × ft	Operation	0 10	0.15	0.20	0.25	0.30	0.35	0.40
30 × 40	Nozzle, inch	3/32	3/32	7/64	1/8	9/64	5/32	5/32
	Pressure, psi	30	50	45	45	45	40	45
	CU, %	69	72	73	75	76	82	85
30 × 50	Nozzle, inch			1/8	9/64	5/32	11/64	11/64
	Pressure, psi			45	50	45	50	55
	CU, %			74	77	80	81	84
30 × 60	Nozzle, inch			9/64	5/32	11/64	3/16	3/16
	Pressure, psi			45	45	45	45	50
	CU, %			60	65	75	80	83
40 × 40	Nozzle, inch			9/64	5/32	11/64	11/64	3/16
	Pressure, psi			35	35	35	50	45
	CU, %			70	72	76	81	84
40 × 50	Nozzle, inch			5/32	5/32	61/64	3/16	13/64
	Pressure, psi			35	50	50	50	50
	CU, %			55	60	70	75	77
40 × 60	Nozzle, inch			5/32	11/64	3/16	13/64	7/32
	Pressure, psi			50	50	50	50	50
	CU, %			64	70	73	74	75
60 × 60	Nozzle, inch						7/32	1/4
	Pressure, psi						80	68
	CU, %						66	75

C0685.72

Table C0685.72 Head Bars Correction Factors for Multiple Outlets

Outlets (number)	Value of 'F'	Outlets (number)	Value of 'F'	Outlets (number)	Value of 'F'
1	1.000	11	0.392	21	0.369
2	0.634	12	0.388	22	0.368
3	0.528	13	0.384	23	0.367
4	0.480	14	0.381	24	0.366
5	0.451	15	0.379	25	0.365
6	0.433	16	0.377	26	0.364
7	0.419	17	0.375	27	0.364
8	0.410	18	0.373	28	0.363
9	0.402	19	0.372	29	0.363
10	0.396	20	0.370	30	0.362
- -	- - -	- -	- - -	>30	0.360

Table C0685.73 Friction Loss (ft/100 ft) in Lateral Lines of Portable Aluminum Pipe with Couplings

(Based on Scobey's formula and 30-foot pipe lengths) 1/

Flow (gpm)	2-inch 2/ K_s = .34	3-inch 2/ K_s = .33	4-inch 2/ K_s = .32	5-inch 2/ K_s = .32	6-inch 2/ K_s = .32
100	25.4	3.20	0.739	0.244	0.099
120		4.54	1.04	.339	.140
140		6.09	1.40	.454	.188
160		7.85	1.80	.590	.242
180		9.82	2.26	.733	.302
200		12.0	2.76	.896	.370
220		14.4	3.30	1.07	.443
240		16.9	3.90	1.26	.522
260		19.7	4.54	1.47	.608
280		22.8	5.22	1.70	.700
300		25.9	5.96	1.93	.798
320		29.3	6.74	2.18	.904
340		32.8	7.56	2.45	1.02
360		36.6	8.40	2.74	1.13
380		40.6	9.36	3.03	1.26
400		44.7	10.3	3.34	1.38
420			11.3	3.66	1.51
440			12.3	4.00	1.66
460			13.4	4.35	1.80
480			14.6	4.72	1.95
500			15.8	5.10	2.12
550			18.9	6.12	2.52
600			22.2	7.22	2.98
650			25.9	8.40	3.46
700			29.8	9.68	3.99
750			33.8	11.0	4.54
800				12.5	5.15
850				14.0	5.78
900				15.6	6.44

1/ For 20-foot pipe lengths, increase values in the table by 7.0 percent. For 40-foot lengths, decrease values by 3.0 percent.

2/ Outside diameter.

Table C0685.74 Center Pivot Irrigation Systems

Percent of Water Applied in Last 100 feet 1/	Total System Length (feet) 2/	Total Area of Square Field Twice the Length of the System (acres)	Area Covered in Acres 3/	
			With Gun Sprinkler Used Only in Corners	With Gun Sprinkler Used on Entire Circle
36.0	500	23.0	22.0	26.0
33.1	550	27.8	26.2	30.5
30.6	600	33.1	30.8	35.3
28.4	650	38.8	36.0	40.6
26.5	700	45.0	41.3	46.2
24.9	750	51.7	47.2	52.1
23.4	800	58.8	53.3	58.4
22.1	850	66.3	59.8	65.1
21.0	900	74.4	66.7	72.1
19.9	950	82.9	74.0	79.5
19.0	1000	91.8	81.7	87.3
18.1	1050	101.2	89.5	95.4
17.4	1100	111.1	98.0	103.9
16.6	1150	121.4	106.6	112.7
16.0	1200	132.2	115.7	121.9
15.4	1250	143.5	123.8	131.4
14.8	1300	155.2	134.0	141.4
14.3	1350	167.4	145.0	151.6
13.8	1400	180.0	155.2	162.3
13.3	1450	193.1	166.5	173.3
12.9	1500	206.6	177.7	184.6

1/ Less volume of end gun when used.
2/ Generally outside drive wheel is approximately 50 feet from end.
3/ Based on 100-foot gun coverage.

C0685.75

Table C0685.75 Nozzle discharge and wetted diameters for typical 1/2- and 3/4-inch bearing impact sprinklers with trajectory angles between 22° and 28° and standard nozzles without vanes.1/

Sprinkler pressure	Nozzle diameter—inch																	
	3/32		7/64		1/8		9/64		5/32		11/64		3/16		13/64		7/32	
psi	gpm	ft	gpm	ft	gpm	ft	gpm	ft	gpm	ft	gpm	ft	gpm	ft	gpm	ft	gpm	ft
20	1.14	63	1.55	73														
25	1.27	64	1.73	76	2.25	76	2.88	79	3.52	82		[2]						
30	1.40	65	1.89	77	2.47	77	3.16	80	3.85	85	4.64	88	5.50	91	6.50	94	7.58	96
35	1.51	66	2.05	77	2.68	78	3.40	81	4.16	87	5.02	90	5.97	94	7 06	97	8 25	100
40	1.62	67	2.20	78	2.87	79	3.64	82	4.45	88	5.37	92	6 40	96	7.55	99	8.82	102
45	1.72	68	2.32	79	3.05	80	3.85	83	4.72	89	5 70	94	6.80	98	8.00	101	9 35	104
50	1.80	69	2.45	80	3.22	81	4.01	84	4.98	90	6.01	95	7.17	100	8.45	103	9.88	106
55	1.88	70	2.58	80	3.39	82	4.25	85	5.22	91	6.30	96	7 52	101	8 85	104	10.34	107
60	1.98	71	2.70	81	3.54	83	4.42	86	5.45	92	6.57	97	7.84	102	9.24	105	10.75	108
65					3.68	84	4.65	87	5.71	93	6.83	98	8.19	103	9.60	106	11 10	109
70					3.81	84	4.82	88	5.92	94	7.09	99	8.49	104	9.95	107	11.40	110
K_d[3]	0.255		0.346		0.453		0.575		0.704		0.849		1.012		1.193		1.394	

[1] The use of straightening vanes or special long discharge tubes increases the wetted diameter by approximately 5%.
[2] Lines represent upper and lower recommended pressure boundaries.
[3] $q = K_d\sqrt{P}$.

Table C0685.76 Irrigation Pipe Size by SDR

PLASTIC IRRIGATION PIPE (PIP)

Nominal Size (in.)	PIP O.D. (in.)	PIP Inside Diameter by SDR (in.)				
		64	51	41	32.5	26
4.00	4.130	4.001	3.968	3.929	3.876	3.812
6.00	6.140	5.948	5.899	5.840	5.762	5.668
8.00	8.160	7.905	7.840	7.762	7.658	7.532
10.00	10.200	9.881	9.800	9.702	9.572	9.415
12.00	12.240	11.858	11.760	11.643	11.487	11.298
15.00	15.300	14.822	14.700	14.554	14.358	14.123
18.00	18.701	18.117	17.968	17.789	17.550	17.262
21.00	22.047	21.358	21.182	20.972	20.690	20.351
24.00	24.803	24.028	23.830	23.593	23.277	22.895

POLYVINYL CHLORIDE PIPE (PVC)

Nominal Size (in.)	PVC O.D. (in.)	PVC Inside Diameter by SDR (in.)			
		41	32.5	26	21
1.00	1.315	- -	- -	1.195	1.189
1.50	1.900	- -	- -	1.754	1.720
2.00	2.375	- -	- -	2.193	2.149
2.50	2.875	- -	- -	2.655	2.601
3.00	3.500	- -	- -	3.230	3.166
4.00	4.500	- -	4.280	4.154	4.072
6.00	6.625	- -	6.299	6.115	5.993
8.00	8.625	- -	8.208	7.964	7.808
10.00	10.750	- -	10.226	9.924	9.728
12.00	12.750	- -	12.128	11.770	11.538

IRON PIPE SIZE (IPS)

Nominal Size (in.)	IPS O.D. (in.)	IPS Inside Diameter by SDR (in.)					
		64	41	32.5	26	21	13.5
0.50	0.840	- -	- -	- -	- -	- -	0.716
0.75	1.050	- -	- -	- -	- -	0.950	0.894
1.00	1.315	- -	- -	- -	- -	1.190	1.120
1.25	1.660	- -	- -	1.558	1.532	1.502	1.414
1.50	1.900	- -	- -	1.783	1.754	1.719	1.619
2.00	2.375	- -	- -	2.229	2.192	2.149	2.023
2.50	2.875	- -	- -	2.698	2.654	2.601	2.449
3.00	3.500	- -	3.329	3.285	3.231	3.167	2.981
4.00	4.500	4.359	4.280	4.223	4.154	4.071	3.833
5.00	5.563	5.389	5.292	5.221	5.135	5.033	
6.00	6.625	6.418	6.302	6.217	6.115	5.994	
8.00	8.625	8.355	8.204	8.094	7.962	7.804	
10.00	10.750	10.414	10.226	10.088	9.923		
12.00	12.750	12.352	12.128	11.965	11.769		

O.D. = Outside Diameter.

C0685.77

Table C0685.77 Pressure Loss in Center Pivot Systems (psi)

System Lateral Length (feet)	Pipe Size (10 gage) (inches) O D	I.D.	Flow Rate at Pivot (gpm) 300	400	500	600	700	800	900	1000	1100	1200
600	4.5	4.231	10 8	18.6	28 4	40.2	53 9	69.5	86 9	106 1	127.2	130 1
600	5	4.731	6.2	10.8	16.5	23.3	31.2	40.2	50.3	61.4	73 6	86.8
700	5	4.731	7.3	12.6	19.2	27.1	36.4	46.9	58 6	71 6	85 9	101 3
700	6	5 731	2.8	4 9	7.5	10.6	14.2	18.3	22.9	28.0	33.5	39 6
800	5	4.731	8.3	14.4	21 9	31 0	41.6	53 6	67 0	81.9	98.1	115 8
800	6	5.731	3.2	5.6	8.6	12.1	16.2	20.9	26.2	32.0	38.3	45 2
900	5	4.731	9.3	16.1	24.7	34.9	46.8	60.3	75 4	92 1	110.4	130 2
900	6	5.731	3.7	6.3	9.6	13.6	18.3	23.6	29.5	36.0	43.1	50.9
900	6 5/8	6.356	2.2	3 8	5.8	8.2	11.0	14.2	17.7	21.7	26.0	30 6
1000	5	4.731	10.4	17.9	27.4	38.8	52.0	67.0	83.8	102.3	122.6	144 7
1000	6	5.731	4.1	7 0	10.7	15 2	20.3	26.2	32.7	40 0	47 9	56.5
1000	6 5/8	6.356	2.4	4.2	6.5	9.1	12.2	15.8	19.7	24.1	28.9	34.0
1100	5	4.731	11.4	19.7	30.2	42 6	57.2	73.7	92.1	112 6	134 9	159.2
1100	6	5.731	4.5	7.7	11.8	16.7	22.3	28.8	36.0	44.0	52.7	62.2
1100	6 5/8	6.356	2.7	4.6	7.1	10.0	13.5	17 3	21.7	26.5	31 7	37 5
1200	5	4.731	12.5	21.5	32.9	46.5	62.4	80.4	100.5	122.8	147.2	173 6
1200	6	5.731	4.9	8.4	12.9	18.2	24 4	31.4	39.3	48 0	57 5	67 9
1200	6 5/8	6.356	2.9	5.1	7.7	10.9	14.7	18.9	23.7	28.9	34.6	40 9
1300	6	5.731	5.3	9.1	13.9	19.7	26 4	34.0	42 6	52.0	62.3	73.5
1300	6 5/8	6.356	3.2	5.5	8.4	11.9	15.9	20.5	25.6	31.3	37.5	44 3
1300	7	6.731	2.4	4.1	6.3	9.0	12.0	15.5	19.4	23 6	28.3	33.4
1400	6	5.731	5.7	9.8	15.0	21.2	28.4	36.6	45.8	56.0	67.1	79 2
1400	6 5/8	6.356	3.4	5.9	9.0	12.8	17.1	22.1	27.6	33 7	40.4	47.7
1400	7	6.731	2.6	4.5	6.8	9.6	12.9	16.7	20.8	25.5	30 5	36.0
1500	6	5.731	6.1	10.5	16.1	22 7	30.5	39 3	49.1	60 0	71 9	84.8
1500	6 5/8	6.356	3.7	6.3	9.7	13.7	18.3	23.6	29.6	36.1	43.3	51.1
1500	7	6.731	2.8	4 8	7.3	10.3	13.9	17 9	22 3	27 3	32.7	38 6
1600	6	5.731	6.5	11.2	17.1	24.2	32.5	41.9	52.4	64.0	76.7	90.5
1600	6 5/8	6.356	3.9	6.8	10.3	14.6	19.6	25.2	31 5	38 5	46.2	54 5
1600	7	6.731	3.0	5.1	7.8	11.0	14.8	19.0	23 8	29.1	34.9	41 1

Hf = L/100 * Ks * .12184 * (GPM^1.9) / (I.D.^4.9)
Ks = 0.34

Table C0685.78 Water Application Per Plant
(gallons/day)

Plants per Acre		60	100	150	200	300	400	500	1000	5000
Sq. Ft. per Plant (100 % Cover)		720	433	290	218	145	110	87	43	8.7
Percent Cover	Water Use (in/day)	Water to Apply (gal/day)								
100	0.03	13.46	8.10	5.42	4.08	2.71	2.06	1.63	0.80	0.16
	0.05	22.44	13.50	9.04	6.79	4.52	3.43	2.71	1.34	0.27
	0.08	35.90	21.59	14.46	10.87	7.23	5.49	4.34	2.14	0.43
	0.10	44.88	26.99	18.08	13.59	9.04	6.86	5.42	2.68	0.54
	0.15	67.32	40.49	27.12	20.38	13.56	10.28	8.13	4.02	0.81
	0.20	89.76	53.98	36.15	27.18	18.08	13.71	10.85	5.36	1.08
	0.25	112.20	67.48	45.19	33.97	22.60	17.14	13.56	6.70	1.36
	0.30	134.64	80.97	54.23	40.77	27.12	20.57	16.27	8.04	1.63
50	0.03	6.73	4.05	2.71	2.04	1.36	1.03	0.81	0.40	0.08
	0.05	11.22	6.75	4.52	3.40	2.26	1.71	1.36	0.67	0.14
	0.08	17.95	10.80	7.23	5.44	3.62	2.74	2.17	1.07	0.22
	0.10	22.44	13.50	9.04	6.79	4.52	3.43	2.71	1.34	0.27
	0.15	33.66	20.24	13.56	10.19	6.78	5.14	4.07	2.01	0.41
	0.20	44.88	26.99	18.08	13.59	9.04	6.86	5.42	2.68	0.54
	0.25	56.10	33.74	22.60	16.99	11.30	8.57	6.78	3.35	0.68
	0.30	67.32	40.49	27.12	20.38	13.56	10.29	8.13	4.02	0.81
25	0.03	3.37	2.02	1.36	1.02	0.68	0.51	0.41	0.20	0.04
	0.05	5.61	3.37	2.26	1.70	1.13	0.86	0.68	0.34	0.07
	0.08	8.98	5.40	3.62	2.72	1.81	1.37	1.08	0.54	0.11
	0.10	11.22	6.75	4.52	3.40	2.26	1.71	1.36	0.67	0.14
	0.15	16.83	10.12	6.78	5.10	3.39	2.57	2.03	1.01	0.20
	0.20	22.44	13.50	9.04	6.79	4.52	3.43	2.71	1.34	0.27
	0.25	28.05	16.87	11.30	8.49	5.65	4.29	3.39	1.68	0.34
	0.30	33.66	20.24	13.56	10.19	6.78	5.14	4.07	2.01	0.41
10	0.03	1.35	0.81	0.54	0.41	0.27	0.21	0.16	0.08	0.02
	0.05	2.24	1.35	0.90	0.68	0.45	0.34	0.27	0.13	0.03
	0.08	3.59	2.16	1.45	1.09	0.72	0.55	0.43	0.21	0.04
	0.10	4.49	2.70	1.81	1.36	0.90	0.69	0.54	0.27	0.05
	0.15	6.73	4.05	2.71	2.04	1.36	1.03	0.81	0.40	0.08
	0.20	8.98	5.40	3.62	2.72	1.81	1.37	1.08	0.54	0.11
	0.25	11.22	6.75	4.52	3.40	2.26	1.71	1.36	0.67	0.14
	0.30	13.46	8.10	5.42	4.08	2.71	2.06	1.63	0.80	0.16

C0685.79

Table C0685.79 Polyethylene Tubing Friction Loss
(ft./100 ft. of Tubing)

0.50 inch Tubing ID = 0.580 in.		0.75 inch Tubing ID = 0.800 in.		0.75 inch Tubing ID = 0.800 in.	
Flow GPH	J ft/100 ft	Flow GPH	J ft/100 ft	Flow GPH	J ft/100 ft
5	0.02	10	0.02	360	8.83
10	0.08	20	0.06	370	9.26
15	0.16	30	0.11	380	9.71
20	0.26	40	0.19	390	10.16
25	0.38	50	0.28	400	10.62
30	0.53	60	0.38	410	11.09
35	0.69	70	0.50	420	11.56
40	0.87	80	0.64	430	12.05
45	1.07	90	0.78	440	12.54
50	1.29	100	0.94	450	13.05
55	1.52	110	1.11	460	13.56
60	1.77	120	1.29	470	14.08
65	2.03	130	1.49	480	14.61
70	2.32	140	1.69	490	15.14
75	2.61	150	1.91	500	15.69
80	2.93	160	2.14	510	16.24
85	3.25	170	2.38	520	16.80
90	3.60	180	2.63	530	17.37
95	3.95	190	2.89	540	17.95
100	4.32	200	3.16	550	18.54
110	5.11	210	3.44	560	19.13
120	5.95	220	3.73	570	19.73
130	6.84	230	4.03	580	20.34
140	7.79	240	4.34	590	20.96
150	8.79	250	4.66	600	21.59
160	9.84	260	5.00	610	22.22
170	10.94	270	5.34	620	22.86
180	12.09	280	5.69	630	23.51
190	13.29	290	6.05	640	24.17
200	14.54	300	6.42	650	24.83
210	15.84	310	6.80	660	25.50
220	17.18	320	7.18	670	26.18
230	18.57	330	7.58	680	26.87
240	20.01	340	7.99	690	27.57
250	21.49	350	8.40	700	28.27

J = 0.133 * Q^1.75 / ID^4.75
Where: Q = Flow Rate in gpm. Note Q = GPH in Table.
ID = Inside Diameter of Tubing in inches.

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Part 686 - Farm Distribution Systems

Part 686 - Farm Distribution Systems

SUBPART A - GENERAL

C0686.1 Purpose of system.

Irrigation water must be made available to each part of the farm irrigation system at a rate and elevation that permits proper operation of the selected method(s) of water application. Irrigation water should be conveyed as economically, efficiently, and safely as possible. The delivery part of the farm irrigation system must be large enough to furnish the required irrigation water to meet crop demands during peak-use periods. If the water is delivered on a rotation or turn basis, the system must be large enough to allow delivery of the water in the time allotted. Plans should provide for future needs and expansion.

C0686.2 Types of systems.

(a) The type of conveyance facilities varies with the method of application. Sprinklers require mains and laterals. Subirrigation uses either ditches or tile. The contour-levee method generally uses a head ditch and levees, and the furrow and border methods require either ditches or pipelines with siphon tubes, gated pipes, or other forms of takeouts.

(b) Conveyance facilities generally are surface ditches, with necessary grade-stabilization and water-control structures, or pipelines. Facilities must be accessible for operation and maintenance and must be able to provide water to every part of an irrigated area. They should be located so that they interfere with farming operations as little as is practical.

C0686.10 Suitability and uses.

(a) The use of pipelines is an efficient method of conveying irrigation water for both surface (low pressure) and sprinkler (pressure) systems. The suitability, characteristics and general requirements for pipeline systems are discussed in National Engineering Handbook, Section 15, Chapter 3, and Engineering Field Manual, Chapter 15. Design criteria, installation requirements, and material specifications for the most commonly used pipeline materials are included in the National Handbook of Conservation Practices (SCS Technical Guide, Section IV). For pump lines, an economic analysis should be made to provide a basis for size selection.

(b) Pipeline delivery systems may consist of a combination of both buried line and surface pipe. A buried mainline may extend from the water source to individual fields and surface pipe used for the field main. This permits moving the field main to other fields. The buried main can also extend into the fields as a field main and have risers and valves appropriately spaced to deliver water to surface ditches or gated pipe.

(c) Gated pipe.

(1) Gated pipes are portable pipes with uniformly-spaced outlets for releasing irrigation water into individual furrows or corrugations. Gated pipe can be used in place of a head ditch at the top of a field, or it can be used in conjunction with the head ditch. It is well suited to use in place of an intermediate head ditch on fields too long to be irrigated in one length of run. This permits cultivation through longer rows since the pipe can readily be moved.

(2) When connected to buried pipelines through hydrants, gated pipes allow the water to be conveyed in an enclosed system from the source to the head of the furrows or borders. Seepage losses are reduced to a minimum. They also provide a convenient means of regulating flow. The gated outlets provide positive control and are especially good if cut-back streams are used. The gates may be slide gates covering either round or rectangular holes in the pipeline. They may be round alfalfa-type valves or round butterfly valves in short sections of proper size tubing connected to the pipe. Flexible sleeves are frequently attached to the gates to aid in distribution and to minimize erosion at the inlet to the rows. Water flow can be regulated by the degree the gates are opened.

Part 686 - Farm Distribution Systems

Subpart C - OPEN CHANNELS

C0686.20 Suitability and uses.

(a) Irrigation ditches are open channels used to carry irrigation water to its point of use. They are used more than any other type of conduit. Small inadequate ditches without proper control structures and maintenance probably are the source of more trouble in operating an irrigation system than any other cause.

(b) Ditches that carry irrigation water from the source of supply to one or more farms are known as canals and laterals. They are generally large and should be permanent installations. Field ditches convey water from the source of supply to a field or fields within the farm unit. They also should be permanent installations.

(c) Head ditches are used to distribute water in a field for surface irrigation. They are laid out at the high end of the irrigation run and are generally perpendicular to the direction of irrigation for furrows and borders. In contour-ditch irrigation the head ditch runs down the slope and water is released to one side or both. Head ditches can be permanent or constructed each irrigation season. The water surface in head ditches should be 0.5 to 1 foot higher than the ground to be irrigated. If possible, the ditches should be nearly level (less than 0.1 ft. fall per 100 ft.) so that water can be backed up for a maximum distance, thus requiring a minimum of check dams and labor to control irrigation flow.

(d) Unlined ditches work best in clay or loam soils since seepage is usually less and ditch banks are more stable than those in sands or sandy loams. Open ditches can carry large volumes of water and have the advantage of low cost per volume of water carried. On soils where seepage and stability are not a problem, they are easy to build.

(e) Ditches have some limitations. Losses from seepage and evaporation can be high, and vegetation and burrowing animals can cause trouble. They take up valuable space and may hinder farm operations. Maintenance requirements are higher than those for pipelines.

C0686.21 Unlined and lined channels.

Ditches may be unlined or lined. A variety of materials are used for lining, the selection of which depends upon climate, soil conditions, costs, and other factors. The types of materials, their suitability, limitations, and general installation requirements are discussed in more detail in National Engineering Handbook, Section 15, Chapter 3, Planning Farm Irrigation Systems. Design criteria, installation requirements, and material specifications for the most common types of lining materials are included in the National Handbook of Conservation Practices.

Part 686 - Farm Distribution Systems

SUBPART D - WATER MEASUREMENT

C0686.30 Need for water measurement.

As the demand for water and energy increases, the need for more efficient use of water increases. In most of the western states, the available water supplies are appropriated and are distributed to users in accordance with their legal rights to its use. Water measurements are essential to the equitable distribution of the supply and to the efficient use of the water.

C0686.31 Methods of water measurement.

(a) The most common methods of water measurement and the types of equipment or structures required are also discussed in National Engineering Handbook, Section 15, Chapter 9, Measurement of Irrigation Water. Some methods discussed in NEH-15 are included in this guide as appropriate. The units of flow commonly used are cubic feet per second (cfs) and gallons per minute (gpm). In certain systems, or districts the terms; inches, feet, acres or shares are used. You must consider these terms carefully because they generally are very localized and may mean different things in different areas.

(b) Open channel flows are measured by one of the following:

(1) Volumetric Flow measurements are made by measuring the time required to fill a known volume.

(2) Submerged orifice plates.

(3) Weirs (Cipolletti, V-notch, rectangular, broad crested).

(4) Flumes (Parshall, cutthroat, V-notch, broad crested).

(5) Siphon tubes.

(6) The float-type by measuring flow cross-sections and flow velocities.

(7) Current meter and calibrated cross-section.

(8) Velocity head rod (jump stick).

C0686.31(c)

(c) Pipe flows are measured by:

(1) Flow meters.

(2) Venturi tubes.

(3) Orifice plates.

(4) Manometers.

(5) Other latest State-of-the-Art techniques.

SUBPART E - WATER CONTROL STRUCTURES

C0686.40 Need for structures.

Water control structures must be an integral part of the farm distribution system to assure proper control and distribution of the water supply, prevent erosion and loss of water. Adequate control structures also reduce labor costs.

C0686.41 Types and suitability of structures.

(a) The types of structures and materials used are dependent on site conditions, the type of distribution system, and the cost of materials. Water control structures are discussed in more detail in National Engineering Handbook, Section 15, Chapter 3, Planning Farm Irrigation Systems and the Engineering Field Manual for Conservation Practices.

(b) Related structures. When open ditch systems deliver water to a surface flood system, it is frequently necessary to provide some type of structure to cross depressions or drains, and under roads or other obstructions as well as to control distribution within or between fields.

(1) Flumes. Flumes are artificial channels supported by substructures which carry water across areas where ditches are not practical. They must be large enough to carry the full discharge of the ditch and the substructures strong enough to support the channel when it is filled with water.

(2) Inverted siphons. Inverted siphons are closed conduits that carry water under depressions, roads, or other obstructions.

(3) Culverts. Culverts are closed conduits installed at ditch grade and commonly used to carry water under farm roads. They are usually made of corrugated metal, but can also be constructed of concrete, plastic, or steel pipe or concrete box culverts.

(4) Grade control. Where the ditch grade is such that the design flow will result in an erosive velocity, some protective structure, such as drop spillway, or pipe drop, must be used. These structures control ditch velocity by lowering the water abruptly from a higher to a lower level. This flattens the grade in the flow sections of the ditch thus lowering the velocity. A pipe drop has an advantage in that it can also serve as a ditch crossing.

(5) Distribution structures. Distribution structures are required for easy and accurate distribution of water to farms and fields or to parts of a field. These may consist of division boxes to divide or direct the flow between two or more ditches, checks that form adjustable dams to control the elevation of the upstream water surface so that water can be diverted from the ditch, or turn-out structures.

(6) Application control structures. Various devices can control the flow of water into furrows or borders. Since it is desired to deliver nearly equal flows into a number of rows at one time, use is made of the hydraulic concept that outlets of equal size operating under the same head have equal flows. Flow rates are changed during the irrigation by altering size of the outlets, varying the number of outlets, or changing the operating head over the outlet. The most common type of outlets used are siphon tubes for delivery from open ditches or gates installed in pipe sections for delivery from surface or underground pipelines.

(i) Siphon tubes are usually made of aluminum or plastic. Normal diameters used for furrow or corrugation irrigation range from one-half to two inches. Diameters used for border irrigation range from two inches to eight inches. Various lengths are available, but normally the smaller tubes are either 5.0 or 7.5 feet long. The discharge of a siphon tube depends on the inside diameter, the length, inside roughness, number and degree of bends, and the head under which the tube is operating. When the outlet is submerged, the operating head is the elevation difference between the water surfaces at the entrance and outlet ends of the tube. When the tube is flowing free, the operating head is the elevation difference between the water surface at the entrance and the center of the outlet. When the water supply decreases or is interrupted, standard siphon tubes usually lose their prime. A siphon tube that automatically resumes operation after interruptions in the water supply is a labor-saving device and provides added safety in furrow irrigation.

(ii) Spiles are pipes, 1.0 to 2.5 inches in diameter that distribute water from a ditch into corrugations or furrows. They are set permanently in the head ditch and must be long enough to extend through the bank and linings, if any. Care must be taken to install spiles at the same elevation so that the same flow enters all the rows being irrigated. Spiles are used where the head ditch is nearly level. The water elevation for each set can then be controlled by a check. It should be high enough above the center of the spile opening to deliver the maximum design furrow stream. The water can then be lowered to a point that delivers the cut-back stream through the spiles. Flow can also be controlled by gates at the inlet end.

CO686.50 General

Recovery or recirculating facilities collect irrigation runoff and return it to the same or an adjacent field for irrigation use. Such systems can be classified according to the method of handling runoff or tailwater. If gathered water is returned to a field lying at a higher elevation, or applied to a lower-lying field, it is usually referred to as a return-flow system. The component parts consist of tailwater ditches to collect the runoff, drainageways or waterways to convey water to a central collection area, a sump or reservoir for water storage, a pump, a power unit, and a pipeline or ditch to convey water for redistribution. Under certain conditions where gravity flow can be used, neither pump nor pipeline may be necessary.

CO686.51 Storage

(a) A return flow system will provide for the temporary storage of a given amount of water, and includes the needed pumping equipment and pipeline to deliver the water back into the application system. The sequence system generally will have a pump and only enough pipe to convey the water to the head ditch of the next field. It is frequently possible to plan the farm so that there is enough elevation difference between fields to apply the runoff water to a lower field in sequence by gravity. Recovery systems may also be classified according to whether or not they accumulate and store the runoff water. Systems storing collected runoff water are referred to as "reservoir" systems. Systems which immediately return the runoff water require little storage capacity. They have automatically-cycled pumping systems and are termed "cycling-sump systems." One or more types of systems may be applicable to a given farm. A pump is used where land value is high, water cannot be retained in a reservoir, or water ponding is undesirable. Dugouts or reservoirs are more common and most easily adapted to storage and planned recovery of irrigation tailwater.

C0686.51(b)

(b) A reservoir system collects enough water to be used as an independent supply or as a supplement to the original supply. The reservoir size will depend on whether collected water is handled as an independent supply, and, if not, on the rate water is pumped for re-use. A smaller reservoir is required if the system is used for cut-back irrigation. Reservoirs should be at least 8 and preferably 10-feet deep to discourage growth of aquatic weeds. Side slopes should be 2 or 2.5 feet horizontal for each one foot vertical to prevent sloughing of the soil banks. Where dugouts may be a safety hazard, one end slope should be five-to-one or flatter to provide a way of escape in case of accidents. The reservoir should provide for an unused storage depth of at least 1.0 foot. Special consideration should be provided for water entry into the reservoir in a non-erosive manner.

C0686.52 Pumps

(a) The cycling-sump system consists of a sump and a pump large enough to handle the expected rate of runoff that enters the sump. The sump is generally a vertical concrete or steel tube with a concrete bottom. The tube is approximately 48 inches in diameter and installed to a depth of approximately 10 feet. Pump operation is controlled automatically by a float-operated or electrode-operated switch. Some storage can be provided in the collecting ditch.

(b) The size, capacity, location, and selection of equipment for these systems are functions of the main irrigation system, the topographic layout of the field or fields, and the farmer's irrigation practice and desires.

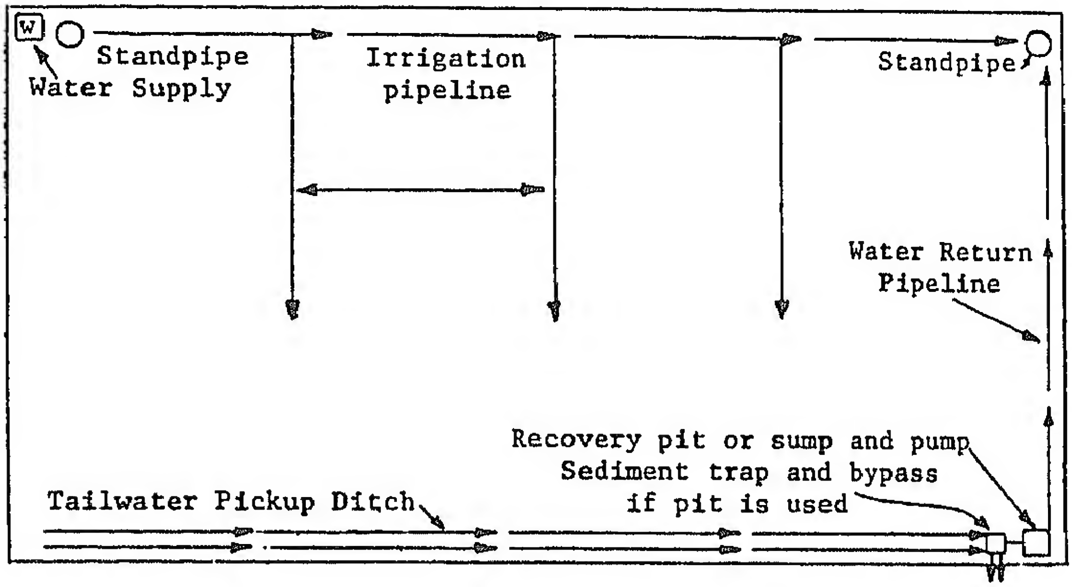

Figure C0686.1 Plan for a Return-Flow System Used in Conjunction with an Underground Pipeline Distribution.

(c) Many different types of pumps can be used with tailwater recovery systems. These include single-stage turbines, hand-primed centrifugals (permanent or tractor-driven), propeller-type or submerged centrifugal (floating pump). Pumps and power units should be matched to the design requirements of the system. The pumping head will generally be low and consequently the horsepower requirements are low (5-10 hp) even for units that discharge reasonably high flow rates. Caution should be used when selecting pump size. For a cycling-sump system when a reuse pump is connected back to the top end of the irrigation system, it is desirable to pump at the lowest continuous rate that will keep up with the quantity of total runoff produced. This will prevent large surges of water that might overload the system (pump, pipeline, head ditch, turnout devices, siphon tubes). For example, it may be better to pump at 500 gpm for an irrigation set time, say 12 hours continuously, than 1000 gpm one-half of the time.

CO686.53 Design procedures

(a) It is necessary that runoff (RO) flows be either measured or estimated to adequately size the cycling sump system, and the recovery pit or dugout. Table CO686.1 indicates expected recovery in gpm based on irrigation head or inflow, and the expected runoff. Expected recovery back to the head of the irrigation system is based on 65% of the runoff. Losses due to seepage, evaporation, overflow and miscellaneous losses do occur in the recovery, storage and pump back system. A furrow flow system evaluation should be used to determine runoff when possible.

(b) Example: Furrow flow analysis gives RO = 35%
Irrigation head or inflow Q = 1000 gpm
Expected recovery (.65)(.35)(1000) = 228 gpm

Use this recovery flow to size the cycling and the sump pump systems. The overflow facilities at the sump should be sized to handle higher peak flow, interruption in power, etc.

(c) When a recovery pit or dugout is used, it should have capacity to store the runoff from one complete irrigation set. The pump capacity will be dependent on the method or schedule of reuse planned. Table CO686.3 provides sizing of pits based on desired pump peak flow and desired set time.

(d) It is most desirable to install a small shallow sediment collection basin at the inlet to the storage pit rather than allow sediment to collect in the storage pit. A shallow basin can be cleaned relatively easy with available farm machinery, where a large pit requires cleaning with contractor-size equipment. Either way, sediment settlement storage must be provided.

GPM 2/ Available	Estimated Runoff 1/ 20%	25%	30%	35%	40%	45%	50%
150	20	24	29	34	39	44	49
200	26	33	39	46	52	59	65
300	39	49	59	68	78	88	98
400	52	65	78	91	104	117	130
500	65	81	98	114	130	146	163
600	78	98	117	137	156	175	195
700	91	114	137	159	182	205	228
800	104	130	156	182	208	234	260
900	117	146	176	205	234	263	293
1000	130	163	195	228	260	293	325
1200	156	195	234	273	312	351	390
1400	182	228	273	319	364	410	455
1600	208	260	312	364	416	468	520
1800	234	293	351	410	468	527	585
2000	260	325	390	455	520	585	650
2200	286	358	429	501	572	644	715
2400	312	390	468	546	624	702	780
2600	338	423	468	592	676	671	845
2800	364	455	546	637	728	819	910
3000	390	488	585	683	780	878	975

Table C0686.1 - Expected recovery in GPM* from Tailwater System.

* Based on 65% recovery of estimated runoff

1/ Estimated Runoff is the percent of water that normally will run out the end of the furrow or border. This is a judgment factor based on such factors as soil type, method of irrigation, efficiency of designed irrigation system and the individual farm operator.

2/ GPM Available is simply the amount of irrigation water that will be supplied to the system being considered. This does not include the tailwater being recovered from this system.

C0685.53(d)

Table C0686.2 Overall Irrigation Efficiency Obtainable with Different Degrees of Tailwater Re-use

		First Re-use			Second Re-use			Third Re-use			Fourth Re-use		
Original Application Efficiency	% of Waste Re-used	% of Original Water Used	Effective Use % of Original	Accumulated Effect	% of Original Water Used	Effective Use % of Original	Accumulated Effect %	% of Original Water Used	Effective Use % of Original	Accumulated Effect %	% of Original Water Used	Effective Use % of Original	Accumulated Effect
60	40	16	9.6	69.6	2.6	1.5	71.1	1.1	.7	71.8	.2	.1	71.9
	60	24	14.4	74.4	5.8	3.5	77.9	1.4	.8	78.7	.4	.2	78.9
	80	32	19.2	79.2	10.2	6.1	85.3	3.3	2.0	87.3	1.0	.6	87.9
50	40	20	10.0	60.0	4.0	2.0	62.0	.8	.4	62.4	.2	.1	62.5
	60	30	15.0	65.0	9.0	4.5	69.5	2.7	1.4	70.9	.8	.4	71.3
	80	40	20.0	70.0	16.0	8.0	78.0	6.4	3.2	81.2	2.6	1.3	82.5
40	40	24	9.6	49.6	5.8	2.3	52.9	1.4	.6	53.5	.3	.1	53.6
	60	36	14.4	54.4	13.0	5.2	59.6	4.7	1.9	61.5	1.7	.7	62.2
	80	48	19.2	59.2	23.0	9.2	68.4	11.0	4.4	72.8	5.3	2.1	74.9
30	40	28	8.4	38.4	7.8	2.4	40.8	2.2	.7	41.5	.6	.2	41.7
	60	42	12.6	42.6	17.8	5.3	49.9	7.5	2.3	52.2	3.1	.9	53.1
	80	56	16.8	46.8	31.4	9.4	56.2	17.6	5.3	61.5	9.8	3.0	64.5
20	40	32	6.4	26.4	10.2	2.1	28.5	3.2	0.7	29.2	1.0	.2	29.4
	60	48	9.6	29.6	23.0	4.6	34.2	11.0	2.2	36.4	5.3	1.1	37.5
	80	64	12.8	32.8	41.0	8.2	41.0	26.2	5.3	46.3	17.5	3.5	49.8

Pumpback Flow gpm	Length of Set			
	6 hour	8 hour	12 hour	24 hour
100	200	267	400	800
200	400	533	800	1600
300	600	800	1200	2400
400	800	1067	1600	3200
500	1000	1333	2000	4000
600	1200	1600	2400	4800
700	1400	1867	2800	5600
800	1600	2133	3200	6400
900	1800	2400	3600	7200
1000	2000	2667	4000	8000

Table C0686.3 - Tailwater Pit Sizing Table (Gallons) for Intermittent Pumpback

To provide for adequate storage (gallons) for intermittent pumpback systems not indicated, use

$$\text{Pond Volume} = \frac{QT}{3}$$

Where Q = volume of pumpback system
T = irrigation set time

Part 686 - Farm Distribution Systems

SUBPART G - AUTOMATION

C0686.60 General

(a) High labor costs have caused many farmers to seek labor-saving devices for their irrigation enterprises. These irrigators are interested in some method of making their systems automatic, or at least, semi-automatic. The first requirement for automation of a furrow system is for it to be properly designed, installed, and maintained. Systems are possible that are completely automatic with re-set features and water sensors that detect the need for irrigation, turn on the water if supplied from farm sources, correctly irrigate the field portion, turn off the water after the irrigation is complete, and re-set so that the system will be prepared for the next irrigation.

(b) Most automated farm systems are semi-automatic with the irrigator deciding when irrigation is needed and delivering the irrigation volume required to the field. Delivery to a field may be by surface ditches or pipelines. Where surface ditches are used, the head ditches are usually lined and check gates are automated so that they are tripped by weight from an accumulation of water in a container that fills slowly from a controlled rate of flow into the vessel. The ditch has a pre-determined grade so that the water will be applied uniformly to the correct number of furrows at a proper design rate. The furrows are irrigated by use of spiles through the ditch, or by use of the fail-safe siphon tubes.

(c) Automation is more commonly used with underground pipe in conjunction with surface gated pipe. Pneumatic valves in hydrants attached to the underground pipe controls the flow to sections of gated pipe. These valves are usually controlled by time clock which simply allows the irrigation to continue for a pre-determined length of time and diverts water to sequencing sets across the field(s).

(d) If farm irrigation systems are to be automated, the following requirements should be met:

(1) The system should be such that failure of the automation will not result in excessive damage to the immediate farm, or other property.

(2) The system should be simple, reliable, and easily-maintained.

(3) It should be economically feasible.

(4) It should irrigate the field efficiently, and distribute water uniformly.

(5) It should be capable of varying irrigation frequency or applying various depths of water in accordance with seasonal plant needs.

(6) Any automatic or semi-automatic surface irrigation system should include provisions for tailwater recovery.

(e) Irrigation frequency can also be controlled by use of sensing or timing devices which sequence the irrigation from one set to the next set by automatically controlling gates or valves in the distribution system. Moisture resistance blocks and tensionmeters are used as sensing devices. Tensionmeters can be used only where soil moisture tensions are less than one-atmosphere. The resistance blocks are capable of measuring a greater range of soil moisture conditions, and therefore, are probably more satisfactory for most uses.

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SUBPART H - DRAINAGE SYSTEM

C0686.70 Surface drainage

(a) Provisions to remove excess water promptly and safely from the irrigated land should be included as an integral part of the design of a farm irrigation system. The excess water may be surface runoff from rainfall or tailwater from irrigation.

(b) Storm runoff must be diverted around or carried through the irrigation system to protect the land, the irrigation system, and crop investment. This may require special erosion control measures such as modifications in the design or layout of the irrigation system. Tailwater from irrigation must be recovered or disposed of without damage to lower lands.

(1) Rainfall runoff. Standard SCS procedures are available to determine the volume and rate of runoff from precipitation. Runoff from precipitation can leave the land through natural water courses. Tailwater or waste ditches are needed at the lower end of irrigation runs to collect rainfall runoff and irrigation tailwater. Storm runoff peaks generally govern the capacity requirements. Where storage and tailwater recovery facilities are provided for irrigation, the storm runoff should bypass the storage reservoir to prevent rapid loss of storage capacity by silt carried by the storm runoff or this condition should be addressed in design and capacity added to offset this event.

(2) Irrigation runoff. Provisions for storage, safe disposal or recovery of tailwater must be included in any graded furrow or corrugation irrigation layout if efficient irrigation is to be achieved. Some states now require that irrigation water not be allowed to trespass on lands not under the control of the irrigator. It is then necessary to provide some means of collecting the tailwater, transporting it to a pit or reservoir, and either store or provide recovery facilities as needed.

C0686.71 Subsurface drainage

(a) Irrigation water applied plus effective precipitation must be in excess of crop evapotranspiration. Most of the excess water percolates below the root zone, and unless the underlying material is sufficiently permeable to allow penetration below drainage depth, a water table may form a few feet below the soil surface and require subsurface drainage facilities. Excess percolation of either irrigation water or rainfall may lead to a high water table that restricts root growth or promotes a saline or alkali condition. Seepage from ditches, reservoirs, and sumps may waterlog adjacent land, requiring tile or open drains to control the water table unless natural internal drainage is adequate. Where drainage facilities are needed, the water table must be held below the root zone to provide aeration and to control salinity. This control is accomplished by means of subsurface drainage which intercepts or accumulates the excess ground water and returns it to the surface.

(b) Subsurface drains are normally designed to lower and maintain the water table at a level ranging from four to eight feet below the ground surface. Subsurface drains are commonly used because the drain must be located according to ground water conditions, which generally do not correspond to field boundaries, fences or property lines. Subsurface drainage systems may consist of interceptor drains, relief drains, or pumped drains.

(1) <u>Interceptor drains</u>. Interceptor drains are used on the more sloping areas with high water table gradients. They are oriented perpendicularly to the direction of ground water flow.

(2) <u>Relief drains</u>. Relief drains are generally used on level to gently-sloping areas with a low water table gradient. They are usually oriented parallel to the direction of ground water flow. Relief drains are usually planned as a series of lateral tile lines in a gridiron or herringbone pattern in which each line is connected to a main that leads to an open drain.

(3) <u>Pumped drains</u>. Pumped drains are used in areas where the soils are underlain by porous sand or gravel aquifers in which the water-table can be lowered by pumping. Detailed subsurface and ground water studies are required to determine the possibility of satisfactorily lowering the water table by pumping. Where there is no natural outlet for interceptor or relief drains, a pumped drain is often incorporated to lift and dispose of the water to an acceptable drainage point.

(c) Detailed information on drainage systems can be found in the Engineering Field Manual, Chapter 14, and in NEH Section 16, Drainage.

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SUBPART A - IRRIGATION TIMING

C0687.1 Determining when to irrigate.

(a) Irrigation is needed when the crop has extracted the allowable amount of moisture from the plant root zone. Typically, the allowable depletion for most crops is 50 percent of the available moisture. Beyond this point plant growth and crop yield are adversely affected. However, potatoes, small vegetables, and some specialty crops require irrigation when only 30 to 40 percent of the available moisture has been removed. Allowable moisture depletion levels for most crops grown in Colorado are shown in Table C0684.2.

(b) The following methods commonly are used to estimate soil moisture content:

(1) Feel and Appearance of Soils. This is a field method of estimating soil moisture without use of special equipment.

(2) Special Moisture Measuring Equipment. This method is the most time consuming, but also the most accurate and is often used to check other methods.

(3) Bookkeeping Methods. This method is based on the daily consumptive use of a crop at predetermined stages of growth. The consumptive use and the rainfall amounts are recorded daily; and when calculated soil moisture reaches a predetermined level, then irrigation is started.

(4) Use of Field Instruments. These are placed in the soil profile at different depths and are usually in the form of tensiometers or electrical resistance blocks.

(c) All methods for determining soil moisture should be considered an aid to judgement.

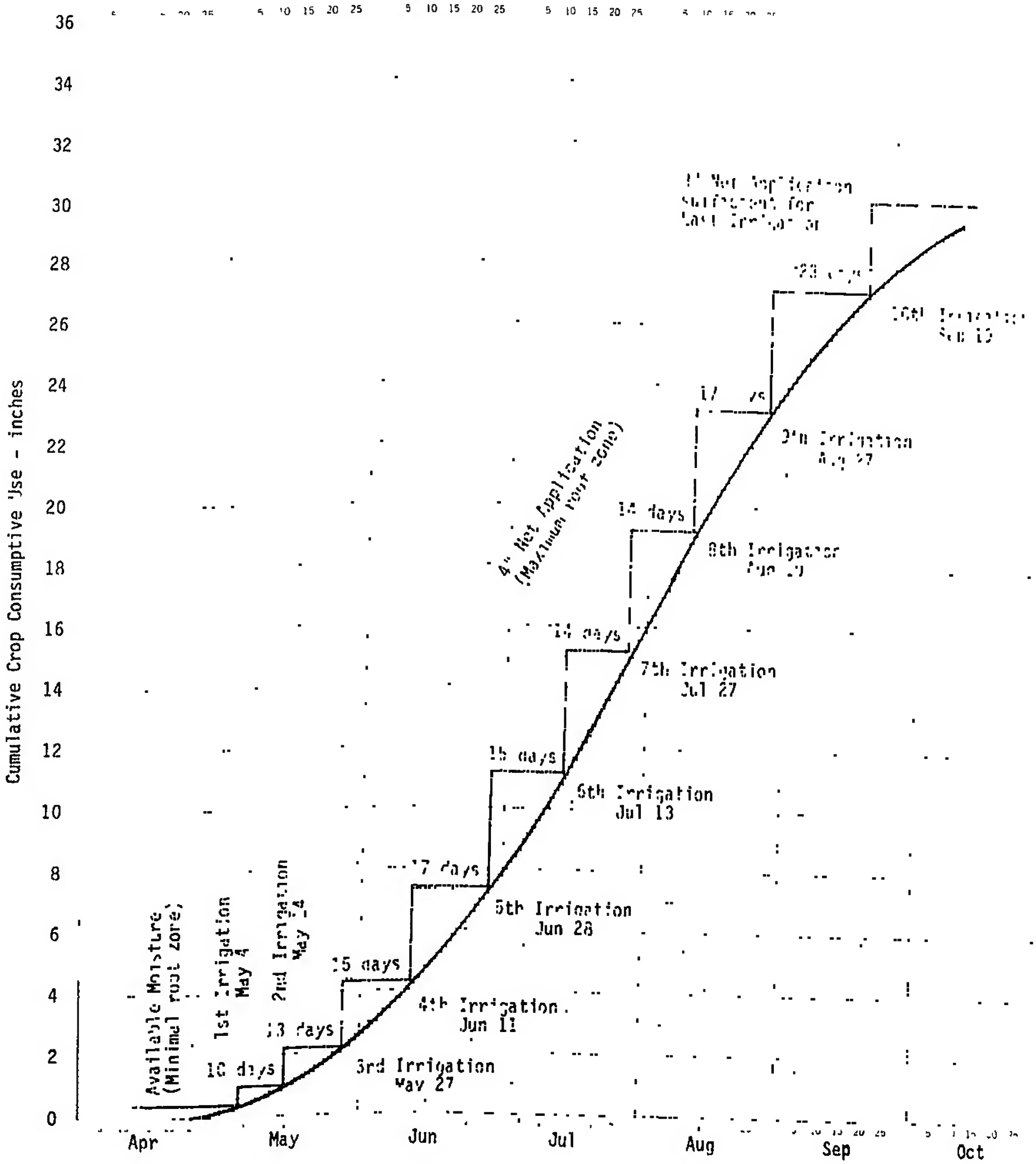
CO687.2 Use of consumptive use mass curve.

(a) The concept of projecting when to irrigate is illustrated by the consumptive use mass curve shown in Figure CO687.1. The curve is for corn being grown for grain at Holly, Colorado. It assumes a full development of a four foot root zone with available moisture capacity, net irrigation requirements, and allowable depletion as indicated. Note that depletion in the top foot can exceed 50 percent due to evaporation losses in excess of moisture extracted by the small plants. The bottom foot may be less than 40 percent depleted because roots are less extensively developed at this depth. Because of these variations we think of an average soil moisture depletion in the root zone as being 50 percent. The curve assumes soil moisture at field capacity prior to planting on April 25, due to winter moisture carry over or to pre-plant irrigation. However, available moisture in the top six inches of soil sustains seed germination and crop evapotranspiration (ET) for about one week. The first irrigation, about May 4, requires about 0.5 inch net application to replenish soil moisture sufficient to last about another week. During this time the plant roots will extend into and extract moisture from the second 6 inches of the soil profile. The second irrigation, about May 14, replenishes soil moisture to the 12-inch depth requiring about a 1.25 inch net application. Available water now should sustain crop growth for about 2 weeks while roots extend into and extract water from a depth of about 24 inches. The third irrigation about May 27, replenishes moisture to the 24-inch depth requiring a net application of 2 inches. Available water should now sustain crop growth for another 2 weeks while roots extend into and extract moisture from a depth of about 36 inches. The fourth irrigation, about June 11, replenishes moisture to the 36-inch depth requiring about a 3-inch net application. Available water should now sustain crop growth for about 2 weeks while roots reach full development to a depth of 48 inches. The fifth and subsequent irrigations replenish moisture to the 48-inch depth requiring about a 4-inch net application. A 3-inch net application is suffcient for the final irrigation. Available water sustains crop growth for diminishing periods of time due to increasing ET rates until late July. As the crop matures the ET rate reduces and less frequent irrigations are needed.

(b) The mass curve, based on long-term average climatic conditions, does not include precipitation, which extends the period between irrigations. Also, hot dry winds or other conditions increase daily ET rates thus reducing the period between irrigations.

(c) Therefore, the farmers need ability to determine actual soil moisture content as influenced by current climatic conditions in order to know when to irrigate.

Figure C0687.1 Consumptive Use Mass Curve Illustrating Projections of Irrigation Dates



Part 687 - Irrigation Water Management

SUBPART B - MEASURING SOIL WATER CONTENT

C0687.10 Feel and appearance method.

(a) A useful method is the feel and appearance method where the amount of moisture in the soil is estimated. No special equipment is required, but a suitable soil auger will aid in obtaining soil samples below the 12-inch depth.

(b) Estimating moisture conditions by feel and appearance is not the most accurate method, but with experience and practice, one should be able to estimate the moisture level within acceptable limits. The descriptions of moisture conditions in Table C0687.1 and photographs in Figure C0687.2 can be used to aid in the determination of moisture present in the soil and the amount that is needed to reach field capacity.

(c) Example.

(1) Assume an Ascalon SL soil is to be irrigated to a 48-inch depth for pasture and samples are taken at the 6-inch, 18-inch, and 36-inch depths. The sample at 36-inch depth is representative of the 24-inch - 48-inch zone. Find the page of Figure C0687.2 showing coarse textured soils and assume moisture condition closely resembling the first photograph for the 6-inch depth, between the second and third for the 18-inch depth, and between the third and fourth for the 36-inch depth. The estimated percent available moisture would then be 25, 50, and 75 percent, respectively.

(2) From Section C0681.20, "Soil Properties for Irrigation", find the Available Water Capacity (AWC).

Soil Depth	AWC (inches)	Moisture Deficit (%)	Needed to Bring to Field Capacity
0-6"	0.96	75	0.72
6-12"	0.90	75	0.68
12-24"	1.46	50	0.73
24-36"	1.18	25	0.29
36-48"	1.63	25	0.41
			2.83 inches

(d) Obtaining samples.

(1) For row crops, measurements should be made on the row near the plants. In sprinkler irrigation, the measuring stations should be between the sprinkler heads and 10 to 15 feet away from the lateral.

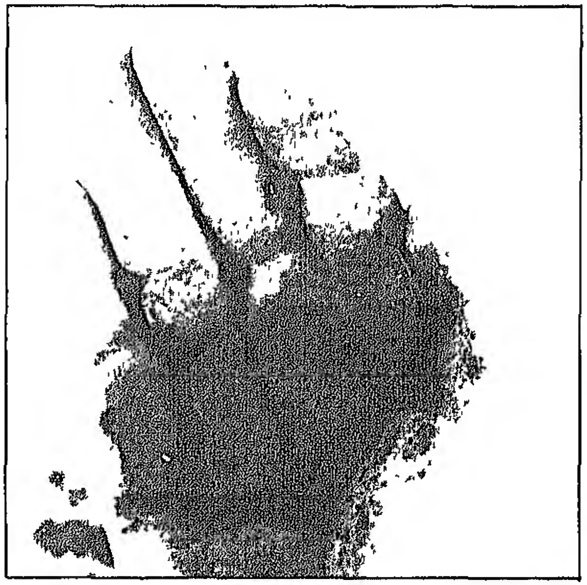
C0685.10(d)(1)

Table C0687.1 Guide for Judging How Much Moisture is Available for Crops

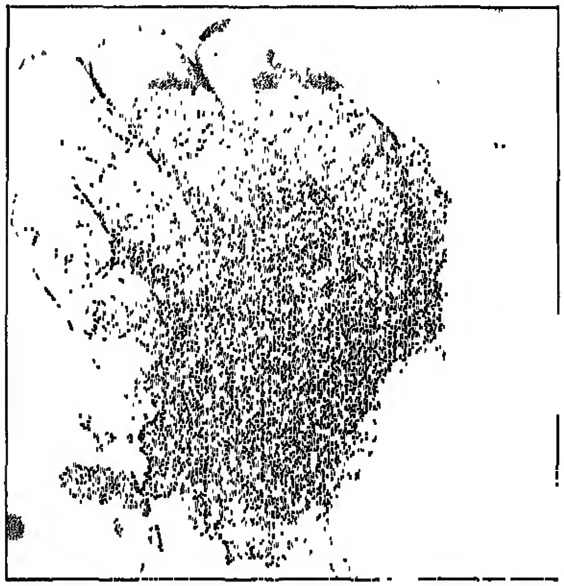
Available soil moisture remaining	Feel or appearance of soil and moisture deficiency			
	Loamy Sand Course Texture	Sandy Loam Moderately Course Texture	Loam and Silt Loam Medium Texture	Clay Loam or Silty Clay Loam Fine and Very Fine Texture
0 to 25 percent	Dry, loose, single grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard baked, cracked, sometimes has loose crumbs on surface.
25 to 50 percent	Appears to be dry, will not form a ball with pressure.1/	Appears to be dry, will not form a ball.1/	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure.1/
50 to 75 percent	Appears to be dry, will not form a ball with pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
75 percent to field capacity (100 percent).	Tends to stick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily is relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity (100 percent)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.

1/ Ball is formed by squeezing a handful of soil very firmly.

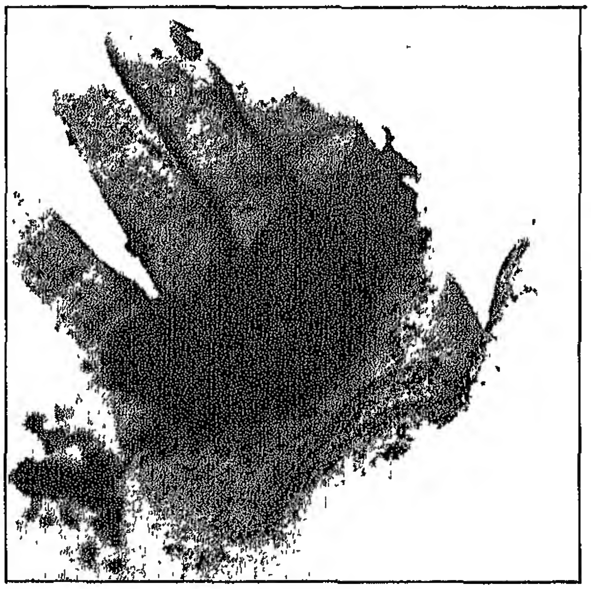
Figure C0687.2(a) Feel and appearance of soils.
Moderately Fine Texture - Clay Loam and Silty Clay Loam.



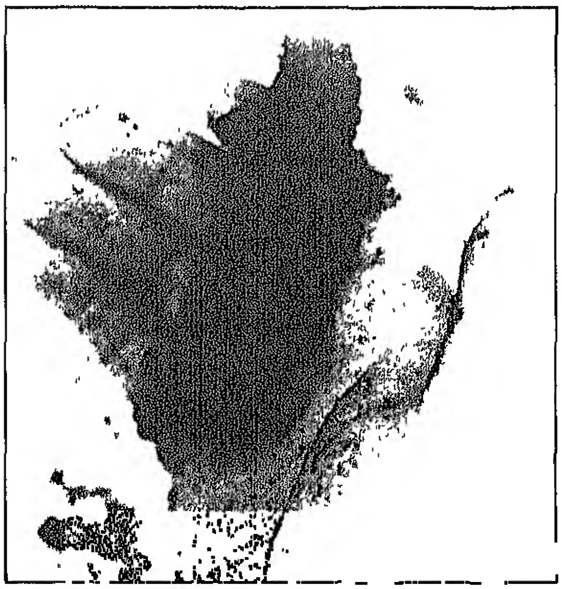
— 0 to 25% Available Moisture —
Crumbles readily, will hold together but "balls" with difficulty and breaks easily.



— 25 to 50% Available Moisture —
Does not crumble, forms readily, will "ball" with pressure.



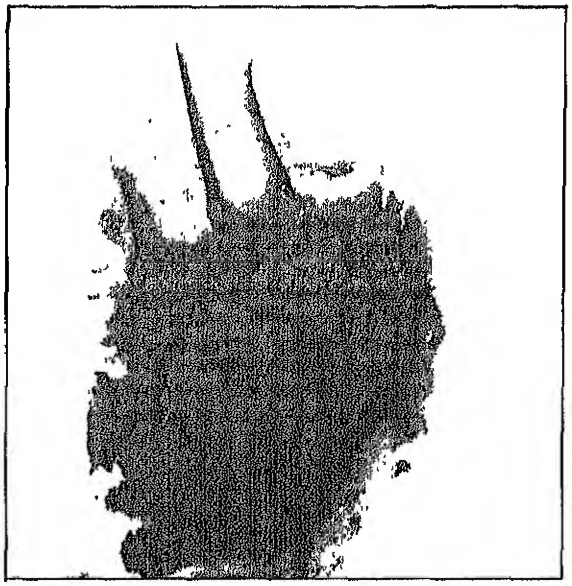
— 50 to 75% Available Moisture —
Forms "ball" readily, will "ribbon" out between thumb and forefinger. Somewhat slick feeling.



— 75 to 100% Available Moisture —
Easily "ribbons" out. Has "slick" feeling.

C0687.10(d)(1)

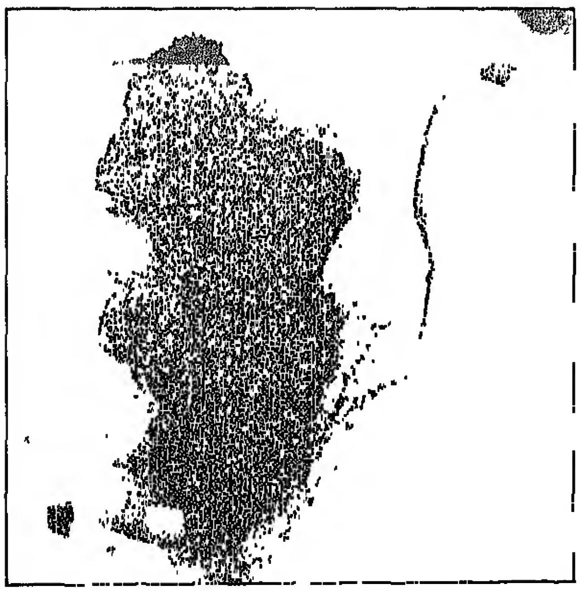
FIGURE C0687.2(b) - Feel and appearance of soils.
Medium Texture - Loams and Silt Loams



— 0 to 25% Available Moisture —
Crumbles easily, tends to hold together from hand pressure.

— 25 to 50% Available Moisture —
Somewhat crumbly, will hold together in hand with pressure.

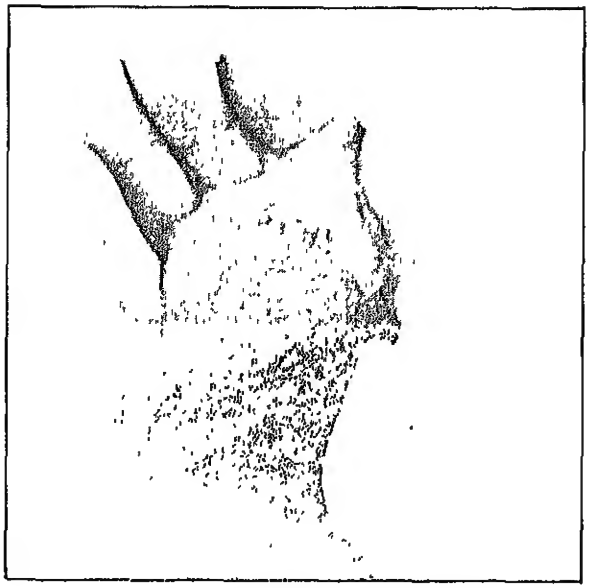
— 50 to 75% Available Moisture —
Forms "ball" readily, will "slick" slightly with pressure.



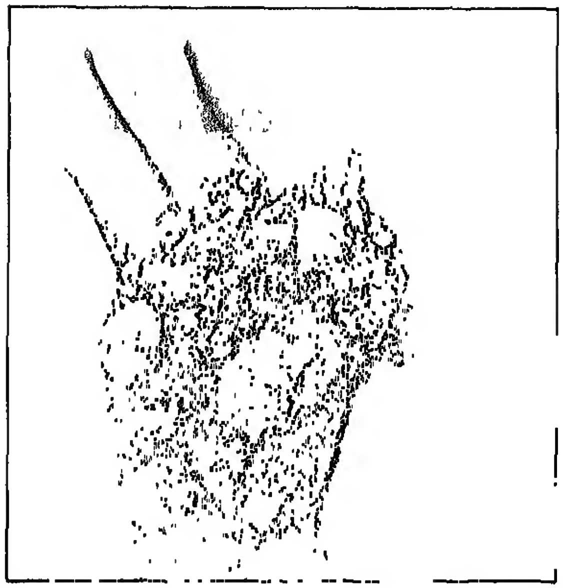
— 75 to 100% Available Moisture —
Forms "ball" easily, fairly friable, "slicks" readily.

C0687.10(d)(1)

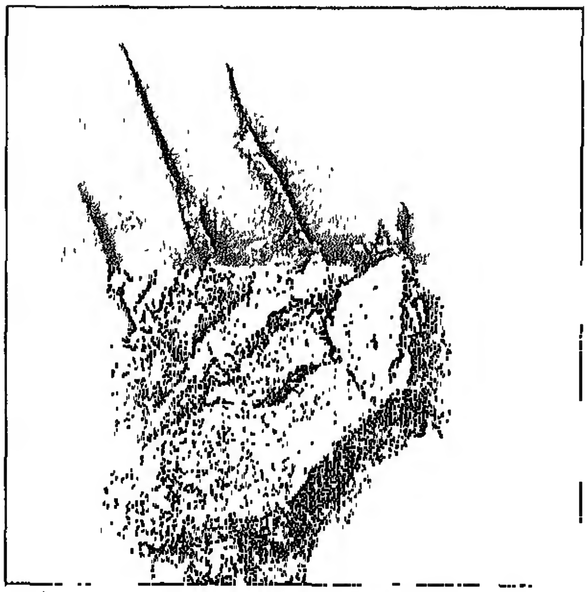
FIGURE C0687.2(c) - Feel and appearance of soils.
Coarse Texture - Sandy Loams and Loamy Sands.



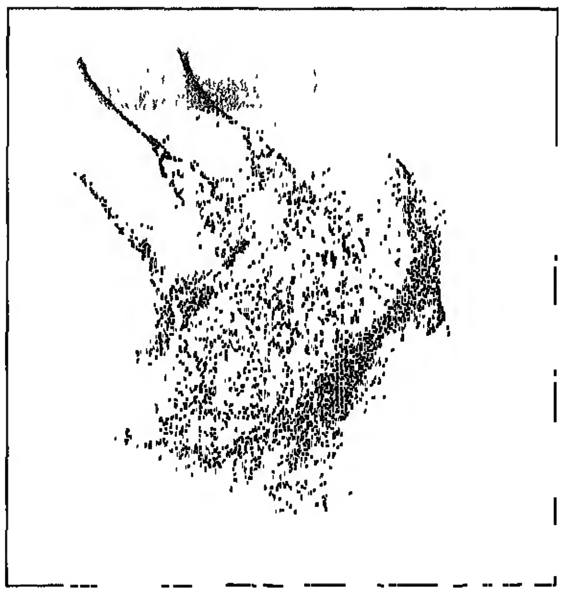
— 0 to 25% Available Moisture —
Dry, loose, flows through fingers.



— 25 to 50% Available Moisture —
Looks dry, will not form ball with pressure.



— 50 to 75% Available Moisture —
Will form loose ball under pressure, will not hold together even with easy handling.



— 75 to 100% Available Moisture —
Forms weak ball, breaks easily, will not "slick."

C0687.10(d)(2)

(2) Measurements should be made in that part of the soil from which plant roots extract their moisture and according to the moisture-extraction pattern of the particular crop. One measurement should be made in the upper quarter of the root zone and one or two additional measurements at lower levels. If the maximum moisture-extraction depth for a given crop is 48 inches, measurements should usually be made at about 6, 18, and 36 inches. To predict when to irrigate during the early stages of root development, the 6 inch measurement is all that is needed for most crops. As the root system reaches maturity, measurements from all three depths are needed for a clear picture of the moisture level throughout the moisture extraction zone.

C0687.11 Gravimetric method.

(a) Equipment required.

(1) Seamless aluminum cans with a capacity of three ounces or more to contain sample for drying.

(2) Triple beam balance with 200-gram capacity, accurate to 0.01 gram.

(3) Drying oven capable of maintaining a temperature of 220°F. to 240°F.

(4) Oven thermometer to check temperature of the oven.

(b) Procedure.

(1) Select a representative sample of the soil to be tested and place in aluminum can. Place the lid on the can. Weigh the wet soil plus the can and record the weight as:
WW = Weight of container + soil + water.

(2) Place the can with soil in the oven with the can open and dry the soil at a temperature between 220°F. to 240°F. until it attains a constant weight. It is important that all moisture be removed from the sample, and may require a time period of 24 hours. If the drying time is less than 12 hours, weigh the sample, replace in the oven for an additional hour, and re-weigh. If there has been no weight change during the second drying, the water content determination will be correct.

(3) Remove the can of oven-dried soil from the oven, cool the container with lid closed, and weigh. Record this weight as:
DW = weight of container + dry soil.

(4) Empty the container, wipe clean, and weigh. Record the weight as: TW = Tare weight of container.

(5) Compute the water content of the soil by the formula:

$$\% \text{ moisture} = \frac{WW - DW}{DW - TW} \times 100$$

(6) An alternative to oven drying is a 250 watt infrared heat lamp. After weighing, empty the sample from the can on a one square foot piece of aluminum foil. After the soil appears dry, pack the soil into a pad about six inches square and place it four inches below the infrared heat lamp for two hours (four hours if air drying is eliminated). Extend the drying time if the sample has not reached constant weight. Be sure the underlying surface is reasonably heat resistant. Compute the percent moisture by the same equation as described in (5) above. Be sure to include the aluminum foil in the tare weight.

(7) An additional alternative is the use of a microwave oven. Wet weight, dry weight and tare weight are determined as described above. The drying process consists of the weighed wet sample in a microwave safe dish being placed in the oven. The oven is turned on for increments of 20-30 seconds and left off for alternating increments of 30-40 seconds. Alternation allows time for residual heat to evaporate moisture without the sample getting hot enough to change its characteristics. After four or five cycles, begin weighing the sample after each cycle. A constant weight after two consecutive measurements represents the dry weight of the sample.

C0687.12 Calcium carbide gas pressure method (speedy moisture tester).

(a) Soil moisture, expressed as a percentage of the dry weight of the soil, is obtained by determining the gas pressure which results when calcium carbide combines chemically with the moisture content of a soil sample. A conversion chart relates gas pressure values to percent moisture on a dry weight basis. A more detailed explanation of the Speedy Moisture Testing method is given in chapter 15 of the Engineering Field Manual.

(b) Equipment required.

(1) Carbide type moisture tester - 26 gram size.

(2) A 26 gram scale for weighing the sample to be tested.

(3) An Eley Volumeter, to determine the volume of the sample to be tested.

(4) Two steel balls weighing approximately 0.4 pounds each.

C0687.12(b)(5)

(5) Calcium carbide reagent.

(6) Calibration curve to convert wet moisture pressure gage reading to dry weight percentage.

(7) Knife.

(c) Procedure.

(1) Place three measures of calcium carbide and two steel balls in the large chamber of the moisture tester. (One scoop for the small 6 gram speedy unit).

(2) Using the Eley Volumeter, obtain an undisturbed sample of the soil profile.

(i) Record the reading on the Volumeter.

(ii) Slowly squeeze out 26 grams of the soil from the Volumeter onto a scale. Use the knife to slice off the correct amount.

(iii) Again read the Volumeter dial to obtain the volume of soil required to produce a 26-gram sample.

(iv) This procedure is for the 26-gram sized moisture meter. If the moisture content of the 26-gram sample exceeds the limit of the pressure gage, a half-sized sample can be used, and the percent indicated on the dial is then doubled.

(3) Place the soil sample in the cap of the tester; then with the pressure vessel in a horizontal position, insert the cap in the pressure vessel and tighten the clamp to seal the cap to the unit.

(4) Raise the moisture tester to a vertical position so the soil in the cap falls into the pressure vessel.

(5) Holding the moisture tester horizontally, manually rotate the device for ten seconds so that the steel balls are put into orbit around the inside circumference, and then rest for 20 seconds. Repeat the shake-rest cycle for a total of three minutes. Do not allow the steel balls to fall against either the cap or the orifice leading to the dial, since this might cause damage.

(6) With the instrument in a horizontal position, read and record the gage pressure. Read the pressure gage to the nearest 0.1 percent. Convert the gauge reading to percent dry weight by use of the conversion chart and record.

(7) Release the pressure slowly, empty the contents, and clean the cap for the next test. When the sample is dumped, examine for lumps. If the soil sample was not completely broken down, increase the shake-rest cycles by one minute on the next test.

(d) Precautions in the Use of the Carbide Type Moisture Tester.

(1) Tests should not be made of saturated high organic soils.

(2) Make a preliminary test of any mineral soil with an unknown maximum water holding capacity using a 13-gram, rather than a 26-gram, sample to reduce the possible pressure generated in the vessel.

(3) In making any test, observe the pressure rise immediately after raising the pressure vessel to a vertical position. The initial pressure increase will be rapid; and after a few seconds, it will be steady until the tester is rotated. If the initial gauge reading approaches 20 percent moisture, (a gauge reading of about 17), release the pressure immediately by loosening the clamp enough to allow the gas to escape.

C0687.13 Tensiometers

(a) The tensiometer consists of a sealed water-filled tube equipped with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. Tensiometers show "soil moisture tension" or soil suction".

(b) The tension generated when the crop roots remove water from the soil draws water from the tensiometer tube through the porous tip and causes the gauge to register a vacuum. The drier the soil, the higher the reading.

(c) When rainfall or irrigation renews the soil water supply, water will enter the tensiometer tube causing the gauge reading to lower.

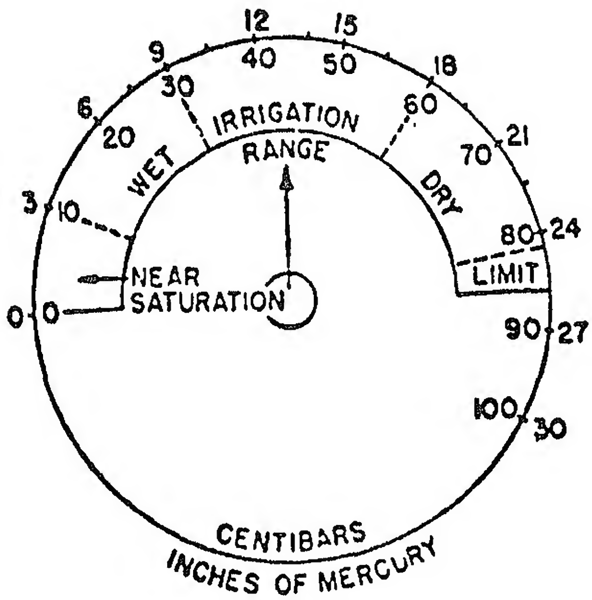


Figure C0687-3. Typical Tensiometer Gauge

(d) Tensiometers are set at a station setting up a zone of moisture control in the soil. A "station" consists of two or more tensiometers of different lengths placed near one another, usually on the crop row.

(e) Two stations may be enough in a field with uniform soil and slope. One station should be near the upper end of the field and the other near the lower end. More tensiometers may be needed in areas where the soils or slopes vary from representative soils or slopes in the field. When placing tensiometers, the following suggestions should be followed:

(1) Tensiometers should be placed on the row and angled toward the furrow. The shallow tensiometer tip should be under the edge of the furrow and the deep tensiometer tip under the center of the furrow.

(2) Measuring stations should be in representative soil areas of the field. Tensiometers should not be placed in low spots in the field.

(3) Stations should be at points where the plant population is representative of the field.

(4) The soil around the tensiometer station should not be compacted. The station should be approached from a row other than the one in which tensiometers are located.

(5) Tensiometers should be placed after the last freeze in the spring and should be removed before the first freeze in the fall.

(f) Depth of installation. Depth of tensiometer installation is determined by the root zone of the crop. This root zone depends upon the crop, stage of growth, and depth of soil. For example, for a crop such as alfalfa on a deep soil, tensiometers installed at a depth of 18 inches and 36 inches are recommended at each station. Recommended depth settings for tensiometers are as follows:

Irrigation Depth of Root Zone	Shallow Tensiometer	Deep Tensiometer
Inches	Inches	Inches
18	8	12
24	12	18
36	12	24
40 or more (deep)	18	36

(g) Determining when to irrigate. The shallow tensiometers at both ends of the field tell when to start irrigating. The gauge reading that indicates need for irrigation will be different for different soils. Guidance for interpreting tensiometer readings are given on page C0687-16.

C0687.13(g)

INTERPRETATION OF TENSIOMETER READINGS

* Dial Reading		Interpretation
Inches of Mercury	Centi-bars	
Saturated 3	0 10	Near saturated soil often occurs for a day or two following irrigation. Danger of waterlogged soils, a high water table, poor soil aeration or the tensiometer may have broken tension, if readings persist.
Field Capacity 6 9	11 20 30	Field capacity. Irrigations discontinued in this range to prevent waste by deep percolation and leaching of nutrients below the root zone. Sandy soils will be at field capacity in the lower range, with clayey soil at field capacity in the upper range.
Irrigation Range 12 15 18	40 50 60	Usual range for starting irrigations. Soil aeration is assured in this range. In general, irrigations start at readings of 30-40 in sandy textured soils (loamy sands and sandy loams). Irrigations usually start from 40-50 on loamy soils, (very fine sandy loams and silt loams). On clay soils (silty clay loams, silty clays, etc.) irrigations usually start from 50-60. Starting irrigations in this range insures maintaining readily available soil moisture at all times.
Dry 21 24	70 80	This is the stress range. However, crop not necessarily damaged or yield reduced. Some soil moisture is readily available to the plant but is getting dangerously low for maximum production. Top range of accuracy of tensiometer, readings above this are possible but the tensiometer will break tension between 80 to 85 centibars.

* Indicative of soil conditions where the tensiometer is located. Judgement should be used to correlate these readings to general crop conditions in the field.

C0687.14 Electrical resistance blocks.

(a) The electrical resistance block system uses small gypsum blocks and a portable resistance meter to measure electrical resistance which can be related to soil moisture content.

(b) Gypsum blocks are made by casting gypsum around a pair of stainless steel wires or wire grids. These wires are attached to lead wires which are plugged into the meter. When the blocks are placed in contact with the soil, the moisture content of the gypsum tends to equal the moisture content of the soil. Because the electrical resistance between the wires in the gypsum varies with the moisture content, a measurement of electrical resistance by the meter is a good indication of the soil moisture content. The drier the soil, the greater the electrical resistance, and vice versa. Erroneous readings may be obtained with high soil salinity. Some meters are constructed so that a low gauge reading indicates low soil moisture and high gauge reading indicates high soil moisture.

(c) Placement of blocks. The location and depth of installation of these blocks is the same as for tensiometers. The blocks should be placed in the rooting zone of the crop as early in the season as is practical and left in the soil throughout the growing season.

(1) The electrical resistance blocks should be thoroughly soaked in a pail of water before installing (follow manufacturer's recommendations for soaking time). Soaking removes air from the blocks and assures accurate readings of the soil moisture.

(2) A soil probe or auger can be used to bore a hole in the row slightly larger than the electrical resistance block. The hole should be angled toward the furrow.

(3) The last three inches of soil removed from the hole should be crumbled and put back into the hole. About 1/2 cup of water should be poured into the hole so a slurry of mud is formed in the bottom.

(4) The blocks should be pushed into the hole with the soil probe, or 1/2 inch diameter electrical conduit, setting them solidly in the bottom with a firm push of the probe. A firm contact between the blocks and surrounding soil must be made.

(5) The hole should then be filled with soil, three or four inches at a time, tamping the soil firmly as the hole is filled.

C0687.14(c)(6)

(6) The wire leads from the blocks should be brought to a single station, midway between the holes and tied to a stake with the wires separated. The wires should be color coded with colored plastic tape or other means of identification.

(d) Meter readings as related to soil moisture.

(1) The following data and the data shown on page C0687-19 are to be used as a guide to interpret meter readings as they relate to soil moisture conditions.

ELECTRICAL RESISTANCE READINGS FOR
STARTING IRRIGATION OF CORN AND GRAIN SORGHUM

Soil Texture	Meter Readings on Shallow Block	
	Meter Reading[1/]	Electrical Resistance
Loamy sands Sandy loams	120	3200
Very fine sandy loams Silt loam	100	4800
Clay loams Silty clay loams	80	7000

[1/] Meter reading allows for five to eight days to complete irrigation.

(2) There will be differences in electrical resistance readings due to frequency of the A. C. resistance meters. Each company that sells electrical resistance meters for measuring soil moisture has recommendations which are provided with its meters.

(e) Determining when to irrigate. The meter readings that indicate the need for irrigation will be different for various textured soils. Irrigation should be started when the average meter readings from the shallow blocks reach the meter readings indicated in the tables.

C0687.14(e)

INTERPRETATION OF READINGS ON ELECTRICAL RESISTANCE METERS

	Electrical resistance		Interpretation
	Ohms	Meter * Readings	
Nearly Saturated	Less than 200	200 to 180	Near saturated soil often occurs for a few hours following irrigation. Danger of water-logged soils, a high water table, poor soil aeration if reading persists for several days.
Field Capacity	300 to 500	180 to 170	Field Capacity. Irrigations discontinued in this range to prevent waste by deep percolation and leaching of nutrients below the root zone.
Irrigation Range	3200 to 7000	120 to 80	Usual range for starting irrigations. Soil aeration is assured in this range. Starting irrigations in this range insures maintaining readily available soil moisture at all times.
Dry	Above 7000	Less than 80	This is the stress range. However, crop not necessarily damaged or yield reduced. Some soil moisture is available to the plant but is getting dangerously low for maximum production.

*Indicative of soil conditions where the electrical resistance block is located. Judgment should be used to correlate these readings to general crop conditions in the field.

C0687.15 Neutron probe.

(a) The neutron probe provides a fast, accurate measurement of the soil water content. The probe is used to monitor the soil water status at the same location, at any depth and frequency desired.

(b) The neutron probe can be used for the following purposes:

- to determine when to irrigate;
- how much to apply;
- moisture extraction by depth for various crops;
- distribution of moisture throughout the field;
- to estimate consumptive use; and
- to determine depth of penetration or rate of movement of water in the soil

(c) To use the neutron probe, it must be calibrated so that readings or count rate is related to actual soil water content. Soils have different chemical properties that affect the neutron readings and, therefore, calibration curves must be developed for each soil series. To calibrate the probe, gravimetric measurements must be made and related to the neutron count.

(d) At each site, permanent access tubes must be installed.

(e) The Federal Nuclear Regulatory Commission (NRC) regulations require a radioactive materials license for the possession and use of reactor produced isotopes. Most agencies require formal training of the users by an approved training agency. Regulations require that nuclear devices by kept in a secure, locked storage area.

(f) The use of the neutron probe is explained in detail in the publication "Soil Moisture Measurement with the Neutron Method" - ARS 41-70, June 1973.

C0687.16 Evaporation methods.

(a) Evaporation Pans - Tubs or large diameter buckets may be rigged as evaporation pans and used to determine soil moisture content, and when to irrigate. Rigging includes a staff gauge with an upper mark indicating field capacity of the soil. A lower mark indicates soil moisture content at the management allowed depletion level. Note that the lower mark must be established after soil moisture content has reached the allowable level of depletion. For example evaporation from the pan may actually be 2.5 inches while the crop removes only 2.0 inches of moisture from the crop root zone. Operation is simple. On the day of irrigation the water level in the pan is raised to the upper mark. Daily observation will reveal the drop in water level indicated by the staff gauge. The water level approaching the lower mark indicates time for irrigation and refilling the pan to bring the water level to the upper mark. A cardinal principle governing the use of evaporation pans is that evaporation is the only cause for water leaving the pan. Therefore, the pan must be protected from thirsty animals and from tipping over.

(b) Atmometers - This device operates much like an evaporation pan. It consists of a small plastic bottle fitted with a stand tube showing water level. Upper and lower marks on the stand tube indicate field capacity and allowable depletion levels for soil moisture. The bottle cap is a porous ceramic tip covered with green canvas material. The green material simulates crop conditions. The ceramic tip simulates crop ET rates so water loss from the bottle is nearly equal to actual crop ET rates. Irrigation is started when the water level approaches the lower mark on the stand tube. When irrigation occurs the bottle is refilled to the upper mark on the stand tube.

C0687.17 Moisture percentage at wilting point.

(a) The methods described in the guide, except for the feel and appearance method, measure total moisture content of the soil. To determine available water capacity, the wilting point (percent moisture) must be determined.

C0687.17(b)

(b) From laboratory or other dependable data, obtain the moisture percentage at 15 atmospheres of soil moisture tension for the type of soil to be irrigated. When laboratory data are not available, the following values may be used:

Texture	Pw
Clay	25
Silty clay	19
Sandy clay	17
Silty clay loam	13
Clay loam	13
Sandy clay loam	11
Silt loam	5.5
Loam	7
Very fine sandy loam	4
Fine sandy loam	4
Sandy loam	4
Loamy fine sand	3
Loamy sand	3
Fine sandy	2
Sandy	2

"Pw" is expressed as percent water on a dry weight basis. The values given do not apply to soils having soil fragments larger than 2.0 millimeters.

C0687.18 Factors affecting amount and use of soil moisture

(a) A number of plant and climatic factors have a marked effect on the amount of water which plants can absorb efficiently from a given soil. Rooting habits, resistance to drought, and stage and rate of growth, are all significant plant factors. Air temperature and humidity are climatic variables which influence the efficiency of utilization of soil water and the amount which can be lost through nonplant channels such as by evaporation from soil surface.

(b) Among the important soil characteristics influencing soil moisture are:

relations

(3) soil depth
(4) soil stratification or layering

(c) The effect of moisture tension on the amount of available moisture in a soil should be obvious. Those factors which affect the amount of water in a soil at field capacity and in turn at the wilting coefficient, will influence the available water. The texture, structure, and organic matter content, all influence the quantity of water a given soil can supply to growing plants. The general influence of texture is shown in Figure C0687.4. Note that as fineness of texture increases, there is a general increase in available moisture storage, although clays frequently have a smaller capacity than do well-granulated silt loams. The comparative available water holding capacities in terms of inches of water per foot of soil are also shown.

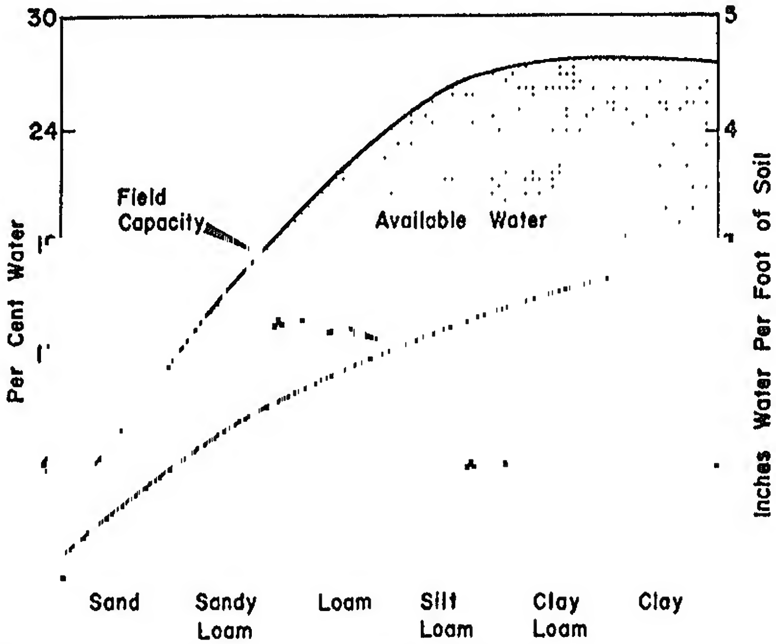


Figure C0687.4 Relationship between soil moisture characteristics and soil texture.

(d) The influence of organic matter deserves special attention. A well-drained mineral soil containing 5 percent organic matter will probably have a higher available moisture capacity than a comparable soil with 3 percent organic matter. The effect is not all due directly to the moisture-holding capacity of the organic matter. Most of the benefits of organic matter is due to its favorable influence on soil structure and, in turn, on soil porosity. Although, humus does have a high field capacity, its wilting point is proportionately high. Thus, the net contribution toward available moisture is minor.

(e) Table C0687.2 can be used as a guide in estimating physical properties of Colorado soils.

C0687.18(e)

Table C0687.2 Estimated Physical Properties of Soils

0 to 12" Soil Layer

Soil Texture	Avg. Bulk Density	Percent Moisture 1/ F.C.	2/ W.P.	3/ A.C.	4/ W.P. F.C.	Inches per Inch 1/ F.C.	2/ W.P.	3/ A.C.
Sand	1.60	8.7	3.5	5.2	40	0.14	0.06	0.08
Loamy sand	1.60	11.9	4.5	7.4	38	0.19	0.07	0.12
Sandy loam	1.55	15.4	5.8	9.6	38	0.24	0.09	0.15
Fine sandy loam	1.50	19.5	7.5	12.0	38	0.29	0.11	0.18
Loam	1.45	23.6	9.2	14.4	39	0.34	0.13	0.21
Silt loam	1.40	27.2	10.9	16.3	40	0.38	0.15	0.23
Silty clay loam	1.35	28.8	13.0	15.8	45	0.39	0.18	0.21
Sandy clay loam	1.40	27.0	13.5	13.5	50	0.38	0.19	0.19
Clay loam	1.40	27.3	15.1	12.2	55	0.38	0.21	0.17
Silty clay	1.30	28.7	18.0	10.7	61	0.37	0.23	0.14
Clay	1.25	29.4	20.1	9.3	68	0.37	0.25	0.12

Below 12"

Soil Texture	Avg. Bulk Density	Percent Moisture 1/ F.C.	2/ W.P.	3/ A.C.	4/ W.P. F.C.	Inches per Inch 1/ F.C.	2/ W.P.	3/ A.C.
Sand	1.70	7.0	3.0	4.0	43	0.12	0.05	0.07
Loamy sand	1.70	10.0	4.2	5.8	42	0.17	0.07	0.10
Sandy loam	1.65	13.4	5.6	7.8	42	0.22	0.09	0.13
Fine sandy loam	1.60	18.2	8.0	10.2	44	0.29	0.13	0.16
Loam	1.55	22.6	10.3	12.3	46	0.35	0.16	0.19
Silt loam	1.50	26.8	12.9	13.9	48	0.40	0.19	0.21
Silty clay loam	1.45	27.6	14.5	13.1	52	0.40	0.21	0.19
Sandy clay loam	1.50	26.0	14.8	11.2	57	0.39	0.22	0.17
Clay loam	1.50	26.3	16.3	10.0	62	0.39	0.24	0.15
Silty clay	1.40	27.9	18.8	9.1	67	0.39	0.26	0.13
Clay	1.35	28.8	20.8	8.0	72	0.39	0.28	0.11

1/ Field capacity
2/ Wilting point
3/ Available water-holding capacity
4/ Percent of field capacity at wilting point

Part 687 - Irrigation Water Management

SUBPART C - WATER BUDGETS

C0687.40 Bookkeeping methods

Various methods are used to determine or forecast time of irrigation based upon historic trends or real time weather data. The first step in using any of the following methods is to determine the soil moisture useable by the crop. All of these methods must be corrected to true soil conditions by periodically verifying field soil moisture.

(a) Moisture accounting method.

(1) Consumptive use values are used to maintain a daily inventory of the moisture remaining in the soil profile. Starting at a time when the moisture level in the soil profile is known a "bookkeeping" system is set up whereby the computed consumptive use is subtracted daily from the recorded available moisture in the profile. Rainfall and irrigation amounts are added to the moisture balance on the days of their occurrence. The success of this method depends on an accurate determination of the waterholding capacity of the soil, daily consumptive use rates, and measurement of rainfall and irrigation amounts.

(2) Consumptive use mass curves are developed by plotting the predicted monthly consumptive use for the particular crop at the end of the given month (see Figure C0687.5). The next month is added to the prior month value and plotted between the points. Monthly plotting paper such as K&E, 1 year by 250 divisions (Figure C0687.6), works well, however, any grid paper can be used.

(3) By determining the available moisture at the start of the growing season and knowing the system application, the approximate date of each irrigation can be determined.

(i) Plot the available moisture at the beginning of the season on the curve developed by (2) above along the vertical axis. By moving horizontally right until this intersects the curve, the date of first irrigation can be approximated.

(ii) From this point, add in the volume of application or allowable soil deficit and extend vertically. Moving across horizontally will give the next approximate irrigation date. This can be projected through the season to approximate irrigation dates.

(iii) The approximation procedure can be refined by adding measurable precipitation to the application amount and selecting the next date.

(iv) This system is useable in approximating irrigation idle periods. The actual conditions will vary from year to year and periodic measurement of soil moisture must be made to recalibrate irrigation periods. Not doing so allows for the possibility of inadequate or excess soil moisture.

(4) Figure C0687.5 reflects approximate scheduling using the above procedure assuming no measurable seasonal precipitation.

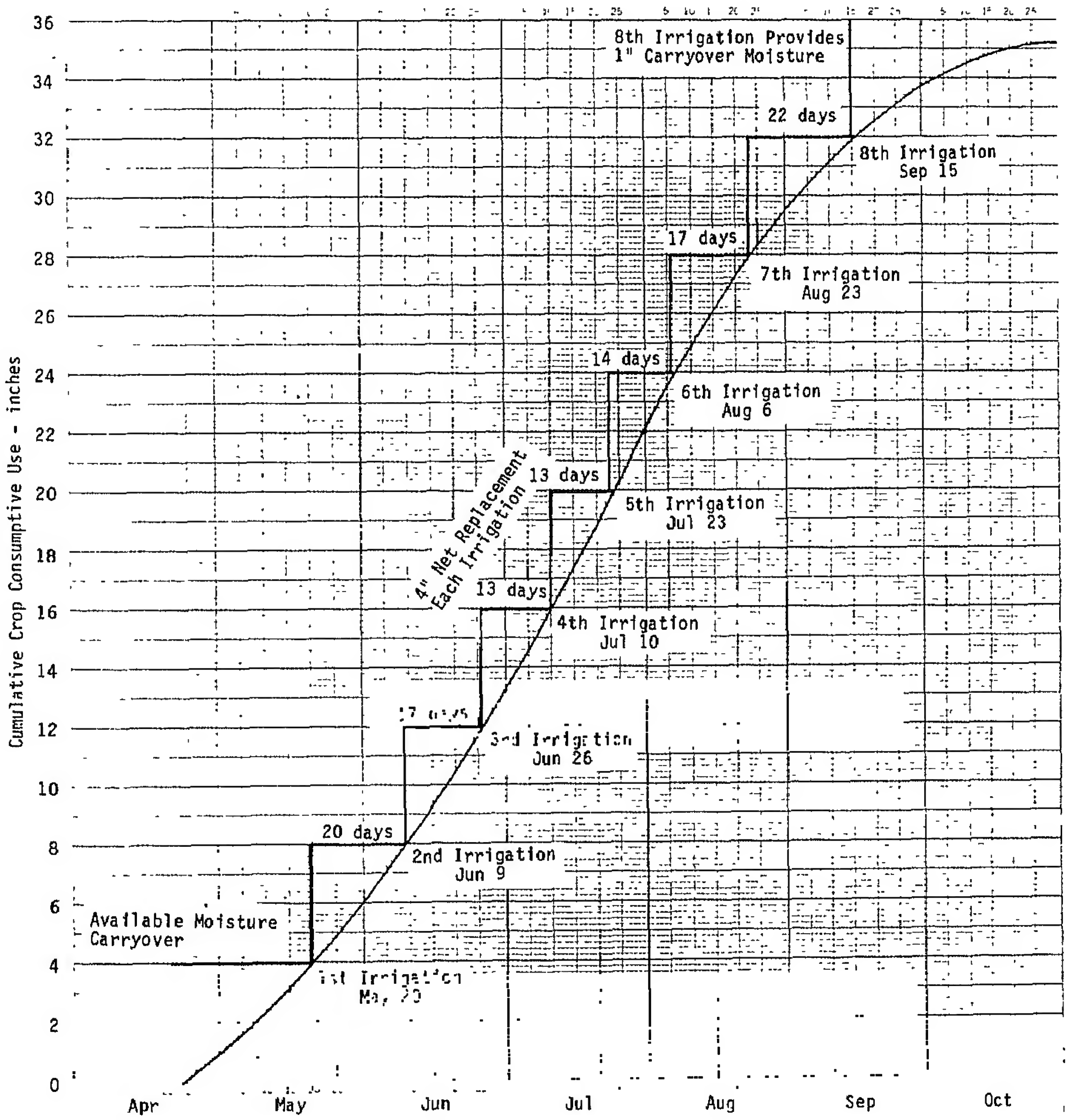
(5) More information on this procedure can be found in the Engineering Field Manual, Chapter 15.

(b) IMS method (evapotranspiration - ET)

(1) The Irrigation Management Service program is conducted in certain areas of the west by the Bureau of Reclamation in Bureau project areas. It is accomplished through the Bureau in cooperation with irrigation and water districts and other water user organizations. It involves scheduling for the purpose of optimum use of irrigation water.

(2) The procedure involves field sampling and laboratory analysis to determine the soil's water-holding capacity. Then, through measurement of local daily temperature, wind, humidity, rainfall, and solar radiation, crop water needs are determined. This is done by a computer program, through use of the Modified Penman equation for calculation of evapotranspiration. With this information, an irrigation schedule can be tailored to a specific site. By combining schedules for several farms, a delivery schedule can be developed for a distribution system.

Figure C0687.5 Consumptive Use Mass Curve Irrigation Scheduling



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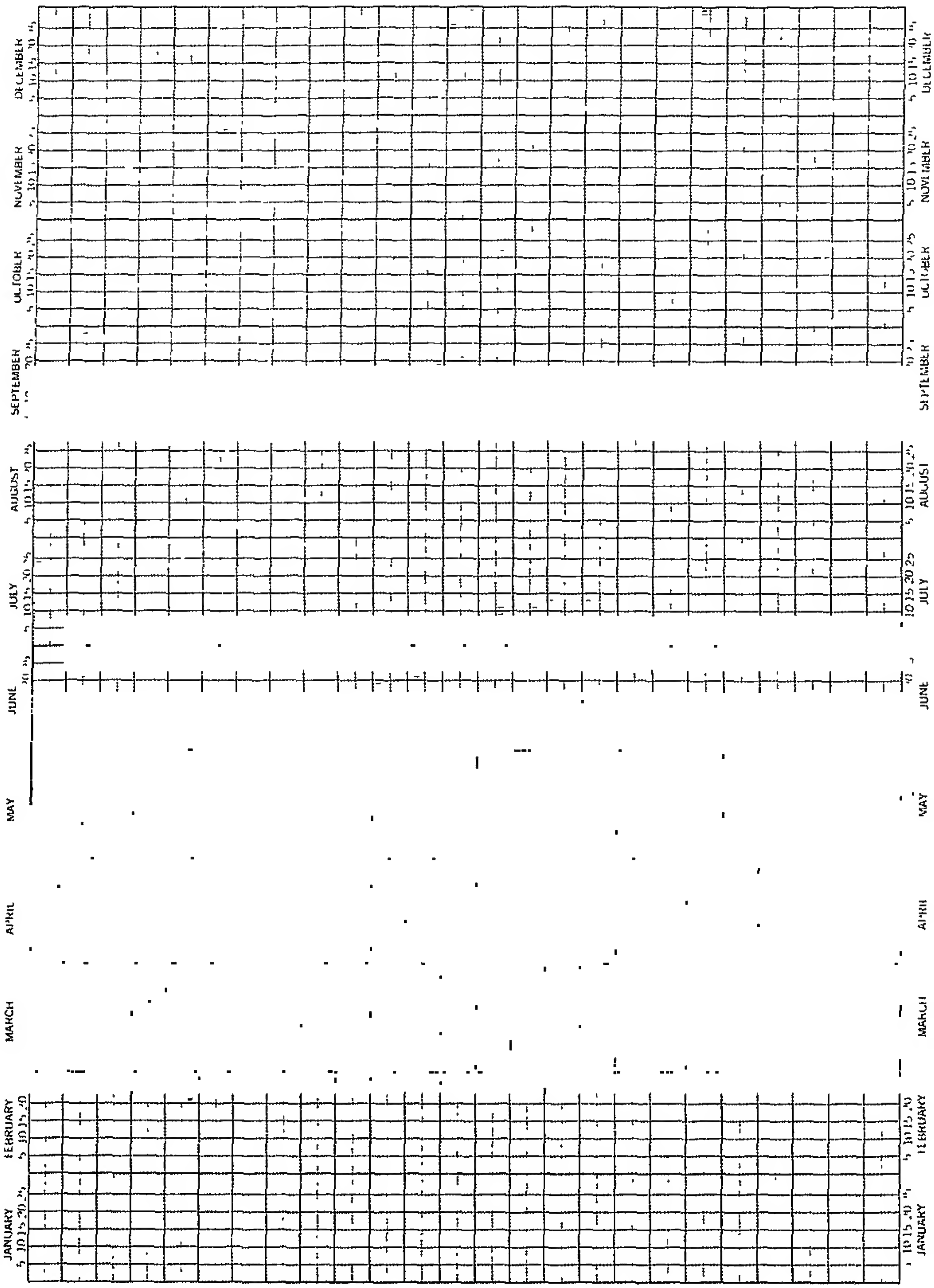
C0687.40(b)(2)

Figure C0687.6 Monthly Grid Paper



C0687.50 General

(a) On site observations and evaluations of irrigation on individual fields are necessary because variations may exist from field to field with similar soils as well as from irrigation to irrigation. The variations may involve soil compaction, cultural practices, soil tilth, and cropping patterns. An evaluation should indicate the relationship between system application rate, amount, and time of application, and compared against the water intake rate and water deficit of the soil that exists during a specific irrigation.

(b) Each method of irrigation has a different method of evaluation. Those included in this guide are for:

(1) Sprinkler irrigation systems

(i) Center pivot system

(ii) Periodic move and solid set systems

(2) Border irrigation system

(3) Furrow irrigation system

(4) Trickle (drip) irrigation system

(c) The basic procedures for conducting irrigation evaluations are included in this guide. More detailed information can be found in the National Engineering Handbook, Section 15.

C0687.51 Sprinkler irrigation systems.

(a) Center pivot.
It is good practice to occasionally test the performance of a center-pivot system to check on the uniformity of application and flow characteristics.

(1) Information required. Center-pivot systems are propelled by using some of the water or by such independent power sources as electricity, oil, hydraulics, or compressed air. Where water is used, it must be included as part of the total applied water; this somewhat lowers computed values of water-use efficiency. When the water discharging from the pistons or turbines is distributed as an integral part of the irrigation pattern, its effectiveness should be included in the uniformity of application or the Distribution Uniformity (DU); otherwise, it should be ignored in the DU computations but should be included in computing the Application Efficiency of the low quarter (E_q).

C0687.51(a)(1)(i)

The following information is required for evaluating center-pivot irrigation systems:

(i) Rate of flow from the total system.

(ii) Depth of water caught in a radial row of catch containers.

(iii) Travel speed of end-drive unit.

(iv) Lateral length to end-drive unit and radius of the portion of the field irrigated by the center pivot.

(v) Width of the wetted strip at end-drive unit.

(vi) Operating pressure and diameter of largest sprinkler or spray nozzles at the end of the lateral.

(vii) Approximate differences in elevation between the pivot and the high and/or low points in the field and along the lateral at the test position radius (taken to within plus or minus 5 feet).

(viii) Additional data indicated on Exhibit C0687.70.

Accurate measurement of the flow rate into the system is needed for determining the application efficiency of the low quarter (E_q) of the system; if no accurate flow metering device is at the inlet, the E_q can only be estimated. One means of estimating is to measure the pressure at the first nozzle and compare to the manufacturers design on relatively new systems. Since flow and pressure are proportional:

$$Q_{est} = Q_{design} \times Pressure_{measured}/Pressure_{design}.$$

(2) <u>Equipment needed.</u> (May also be used for the full evaluation of sprinkler-lateral systems.)

(i) A pressure gauge (0-100 psi) with pitot attachment.

(ii) A stopwatch or watch with an easily visible second hand.

(iii) From 60 to 100 (depending on the lateral length) catch containers such as 1-quart oil cans, plastic freezer cartons, plastic cups, or small rain gauges incremeted in inches.

(iv) A 250-mil graduated cylinder to measure volume of water caught in the containers (not needed when rain gauges are used for catch containers).

(v) A tape for measuring distances in laying out the container row and estimating the machine's speed.

(vi) A hand level and level rod to check differences in elevation.

(vii) A shovel for smoothing areas to set catch containers and for checking profiles of soil, root, and water penetration.

(viii) Exhibit C0687.70 for recording data.

(ix) Manufacturer's nozzle specifications giving size, location, discharge, pressure, and the instructions for setting machine's speed.

(x) Pipe flow meter and 16-foot extension ladder.

(xi) Voltage meter to measure stray currents at towers.

(3) Field procedure. Fill in the data blanks of Exhibit C0687.70 while conducting the field procedure. In a field having a low-growing crop or no crop, test the system when the lateral is in a position where differences in elevation are least. In tall-growing crops, such as corn, test the system where the lateral crosses the access road to the pivot point.

(i) Set out the catch containers along the radial path beginning at the pivot with a convenient spacing no wider than 30 feet; a 15- or 20-ft spacing is preferable. The radial path does not need to be a straight line. A most convenient spacing can be obtained by dividing the span length by a whole number such as 3, 4, 5, 6, etc. For example, if the span length is 90 feet, use a 30-foot or 22.5-foot spacing. This simplifies the catchment layout since measurements can be made from each wheel track and the spacing related to the span, i.e., 4th span = 50 feet. Obviously, containers should not be placed in wheel tracks or where they would pick up waste exhaust water from water-driven systems (where the exhaust is not distributed). Where exhaust water is incorporated into the wetting pattern, lay out containers so they will catch representative samples of the drive water. As an example, a typical layout between wheel tracks for 90-foot spans and any type of drive can be accomplished by:

(a) Placing the first container position 5 feet downstream from the pivot.

(b) Setting the container positions 2, 3, and 4 at 22.5-foot intervals. The fourth container position is now 17.5 feet from the wheel track of the first span.

C0687.51(a)(3)(i)(c)

(c) Repeat the above procedure to the end of the actual wetted circle placing a catch container at each container position along the way.

(ii) To save time it is most convenient to leave out the first few containers adjacent to the pivot since the watering cycle is so long in this area. Typically, the containers under the first one or two spans are omitted with little adverse effect on the evaluation. A number should be assigned to each container position with a sequential number system beginning with one (1) at the container position at the pivot point. Even the locations not having containers under the first spans should be numbered.

(iii) Fill in the blanks (Exhibit C0687.70) dealing with climatic conditions, machine and test specifications, topography, general system, soil moisture, and crop performance. Determine the irrigated area, in acres by first determining the wetted radius of the irrigated circle.

(iv) Determine the length of time required for the system to make a revolution by dividing the circumference of the outer wheel track by the speed of the end-drive unit.

(a) Stake out a known length along the outer wheel track and determine the time required for a point on the drive to travel between the stakes. The speed of travel will be the distance traveled divided by the measured travel time.

(b) Since most machines have uniform span lengths, except perhaps, for the first span, the radius between the pivot and the outer wheel track can normally be determined by multiplying the span length by the number of spans.

(v) Estimate the width of the wetted pattern (perpendicular to the lateral) and the duration of time water is received by the containers near the end-drive unit. The watering time is approximately equal to the pattern width divided by the speed of the end-drive unit. Check against sprinkler nozzle performance taken from manufacturer design.

(vi) If the system is equipped with a flow meter, measure and record the rate of flow into the system on C0687.70. Most standard flow meters indicate only the total volume of water that had passed. To determine the flow rate, read the meter at the beginning and end of a 10-minute period and calculate the rate per minute. To convert from cubic feet per second (or acre-inches per hour to gpm, multiply by 450). A Cox Piro-Swivel Monometer gauge can be used to measure pipe velocity at the first sprinkler head access fitting providing velocity is less than 10 fps.

(vii) When the leading edge of the wetted pattern reaches the test area, set aside two containers with the anticipated catch to check the volume of evaporation losses. Measure and record the depth of water in all the containers as soon as possible and observe whether they are still upright; using a graduated cylinder to obtain volumetric measurements. These can be 1-quart oil cans, 200 ml corresponds to a depth of 1.0 in. Measure the catch of one of the evaporation check containers about midway during the catch reading period and the other one at the end.

(viii) The volumes caught in the containers must be weighted, since the catch points represent progressively larger areas as the distance from the pivot increases. To weight the catches according to their distance from the pivot, each catch value must be multiplied by a factor related to the distance from the pivot. This weighting operation is simplified by using the container layout procedure described in Exhibit C0687.70.

(a) The average weighted system catch is found by dividing the sum of the weighted catches by the sum of the catch position number where containers were placed. Space for this computation is provided in Exhibit C0867.70.

(b) For the average minimum weighted catch, an unknown number of containers that represents the low 1/4 of the irrigated area must by used. The low 1/4 is selected by picking progressively larger (unweighted) catches and keeping a running total of the associated position numbers until the subtotal approximates 1/4 of the sum of all the catch position numbers. The average weighted low 1/4 of the catches is then found by dividing the sum of the low 1/4 of the weighted catches by the sum of the associated catch position numbers.

(c) To determine whether the system is operating at acceptable efficiency, the losses to deep percolation and distribution uniformity should be evaluated by:

$$DU = \frac{\text{average weighted low quarter catch}}{\text{average weighted system catch}} \times 100$$

which for the example problem in Exhibit C0687.71 is:

$$DU = \frac{0.43}{0.50} \times 100 = 86 \text{ percent}$$

This is a reasonable value. DU should be greater than 85%, and is independent of the speed of revolution.

C0687.51(a)(3)(viii)(d)

(d) Plot the volume of catch against distance from the pivot (Figure C0687.7). Such a plot is useful for spotting problem areas and locating improperly-nozzled or malfunctioning sprinklers. Usually, there is excess water near each water-driven drive unit where the water is distributed as part of the pattern.

(e) If the system is operating on a undulating or sloping field and is not equipped with pressure or flow regulators, DU will vary with the lateral position. The DU will remain nearly constant if the differences in elevation (in feet) multiplied by 0.43 (to convert to an equivalent psi) do not exceed 20 percent of the pressure at the end sprinkler. Thus, for the example test the line position would have minimal effect on the DU since the pressure at the end sprinkler was 60 psi and the maximum elevation difference were only 25 feet, equivalent to 11 psi which is only 18 percent of 60 psi. <u>The E_q can be determined if the pivot point is equipped with an accurate flow measuring device.</u> For the average low quarter rate caught, use the average weighted low one-quarter of the catches expressed as a depth per revolution. The average depth of water applied per revolution is calculated by the formula:

$$Q = \frac{453\ Ad}{FH}$$

Q = flow, gpm
A = design area, acres
d = gross depth of application, inches
F = time allowed for completion of one irrigation, days
H = actual operating time, hr/day

and from data computed on Exhibit C0687.71 on lines 11, 14, and 4, the depth applied per irrigation (revolution) is:

$$d = \frac{31.4 \times 1{,}150}{453 \times 152} = 0.53 \text{ inches}$$

$$E_q = DU \times \frac{\text{average weighted system catch}}{d}$$

$$E_q = 86 \times \frac{0.50}{0.53} = 81 \text{ percent}$$

(f) The small difference between DU of 86 percent and E_q of 81 percent indicates that evaporation losses are quite small and within the limits of accuracy of measurements. The system flow rate and E_q can be estimated without a flow meter at the inlet. This is done by first estimating the gross application by adding the average depth caught and the estimated evaporation, which for the data recorded in Exhibit C0687.71, on lines 15 and 17, is 0.50 + .02 = 0.52 inches per revolution. The flow in gpm, which was distributed through the sprinkler, can be estimated by:

$$\text{Distributed flow} = \frac{453 \times 152 \times 0.52}{31.4} = 1{,}140 \text{ gpm}$$

(g) E_q is computed as before by using the computed system flow. For the recorded data the drive water was included in the distributed flow and need not be computed. However, if it had not been included in the distributed flow, it should be estimated by:

$$\text{Drive flow} = \text{gpm flow from end water motor}$$

$$\times \frac{\text{Sum of drive unit numbers}}{\text{number of drive units}}$$

For 15 drive motors and 13.5 gpm flow rate from the end motor

$$\text{Drive flow} = 13.5 \left(\frac{120}{15}\right) = 108 \text{ gpm}$$

$$\text{where } 120 = (1 + 2 + 3 + \ldots + 14 + 15)$$

(4) Runoff. The computation of E_q is meaningful only if there is little or no runoff. Runoff and/or ponding may occur near the moving end of the system. Increasing the system's speed will reduce the depth per application and often prevent runoff. However, on some cracking clay type soils, decreasing the system's speed and allowing the surface to become drier between irrigations will improve the soil infiltration characteristics and reduce runoff, even though the depth per application is increased. Therefore, both increasing and decreasing the speed should be considered. Other methods for reducing runoff include:

(i) Using an implement called a pitter, which scrapes indentations in the furrows followed by small dikes every 2 or 3 feet.

C0687.51(a)(4)(ii)

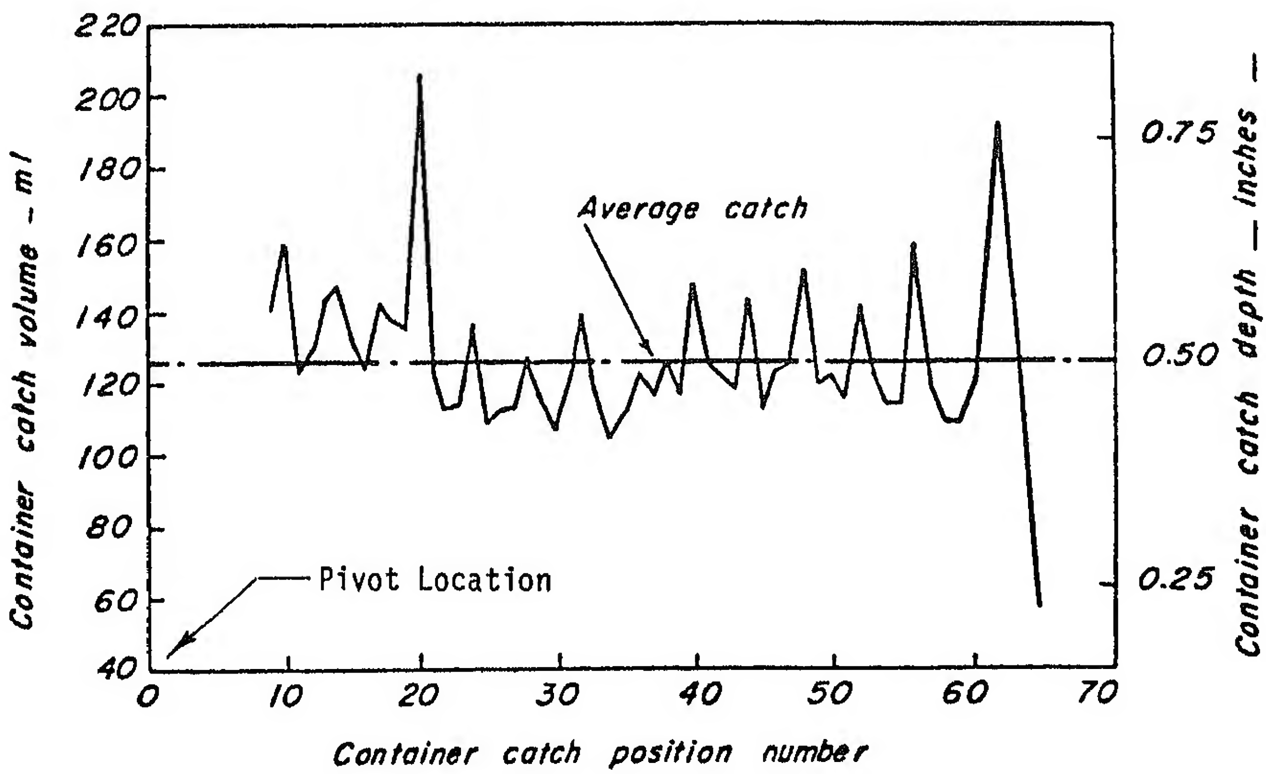
(ii) Reducing the total depth of water applied by turning the system off for a period of time after each revolution. (Automatic stop devices are available for many systems.) This allows the surface soil to become drier between irrigations and in some cases have a higher infiltration capacity. Care is required in order to avoid extensive under-irrigation which can reduce crop yields.

(iii) Decreasing sprinkler nozzle diameters to reduce the system capacity and application rate; all the nozzles must be changed to maintain uniformity. Use of a manufacturers nozzling program is recommended.

(iv) Increasing system pressure and reducing nozzle sizes throughout the system to maintain the same system flow rate. This decreases the drop size and thereby drop impact which reduces the surface sealing that restricts infiltration.

(v) Using special nozzles with pins to break up the jets and reduce drop sizes.

Figure C0687.7 - Profile of container catch from center pivot sprinkler evaluation test. Pivot is located at '0' position.



C0687.52 Periodic-move and solid-set systems.

(a) Successful operation of sprinkler irrigation systems require that the frequency and quantity of water application be accurately scheduled. Field application efficiency must be known to manage the quantity of application. Since system performance changes with time, periodic field checks are recommended. Data from the field evaluation of a periodic-move sprinkler system is presented in Exhibit C0687.73. The procedure for collecting the data follows:

(1) Information required. The desired information includes:

(i) Duration of normal irrigations.

(ii) Spacing of sprinklers along lateral lines.

(iii) Spacing of lateral lines along the main lines.

(iv) Measured depths of water caught in catch containers at a test location.

(v) Duration of the test.

(vi) Water pressures at the sprinkler nozzles at the test location and along laterals throughout the system.

(vii) Rate of flow from the tested sprinklers.

(2) Equipment needed.

(i) A pressure gauge (0-100 psi) with pitot attachment.

(ii) A stopwatch or watch with an easily-visible second hand.

(iii) A large container of known volume clearly marked (one gallon or larger for large sprinklers).

(iv) A 4-foot length of flexible hose having diameter appreciably larger than the outside diameter of nozzles.

(v) From 50 to 100 (or more, depending on sprinkler size) catch containers such as 1-quart oil cans, plastic freezer cartons, or small rain gauges.

(vi) A measuring stick (or ruler) to measure depth, or a 250-ml graduated cylinder to measure volume of water caught in containers.

(vii) A soil probe or auger.

C0687.52(a)(2)(viii)

(viii) A 50- or 100-foot tape for measuring distances in laying out catch container grid.

(ix) A shovel for smoothing spots to set containers and for checking soil, root, and water penetration profiles.

(x) Exhibit C0687.72 for recording data.

(xi) Manufacturers' sprinkler performance charts showing the relationship between discharge, pressure, and wetted diameter plus recommended operating pressure ranges.

(xii) A set of drill bits ranging in size from 3/64 to 1/4-inch in diameter in increments of 1/64-inch makes a handy set of feeler gauges to check nozzle wear on circular orifices. The new "CDS" and "Diffuser" nozzles are more difficult to check for wear. A visual check and a discharge vs. pressure check is reasonable.

(3) Field procedure.

(i) Chose a location along a lateral for the test. It may be either a single location at which the pressure is typical (or average) for the entire system, or two locations near the ends of a lateral to permit study of effects of differences in pressure. Loss of pressure due to friction in a lateral that has only one size of pipe is such that about half of the pressure loss occurs in the first 20 percent of the length and over 80 percent of the pressure loss occurs in the first half of the lateral's length (See Figure C0687.8). On a flat field, the most representative pressure is about 40 percent of the distance from the inlet to the terminal end.

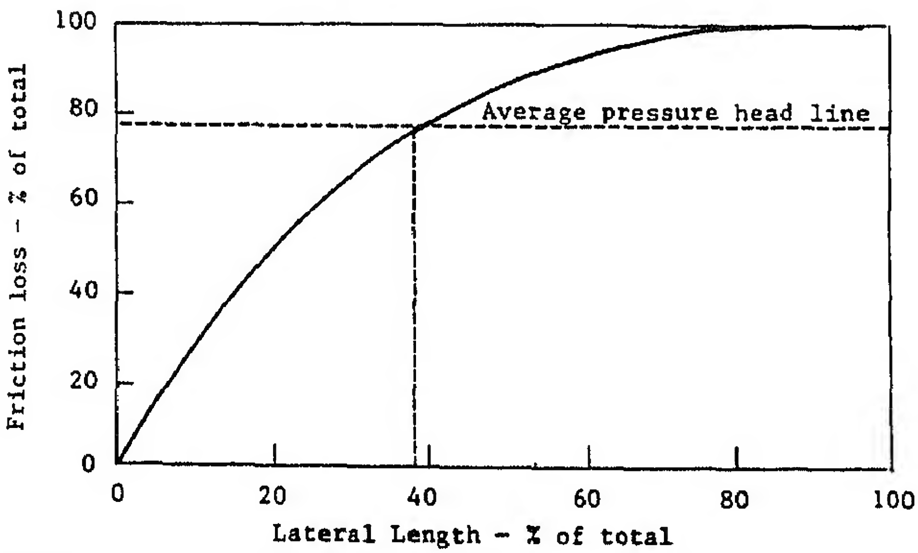


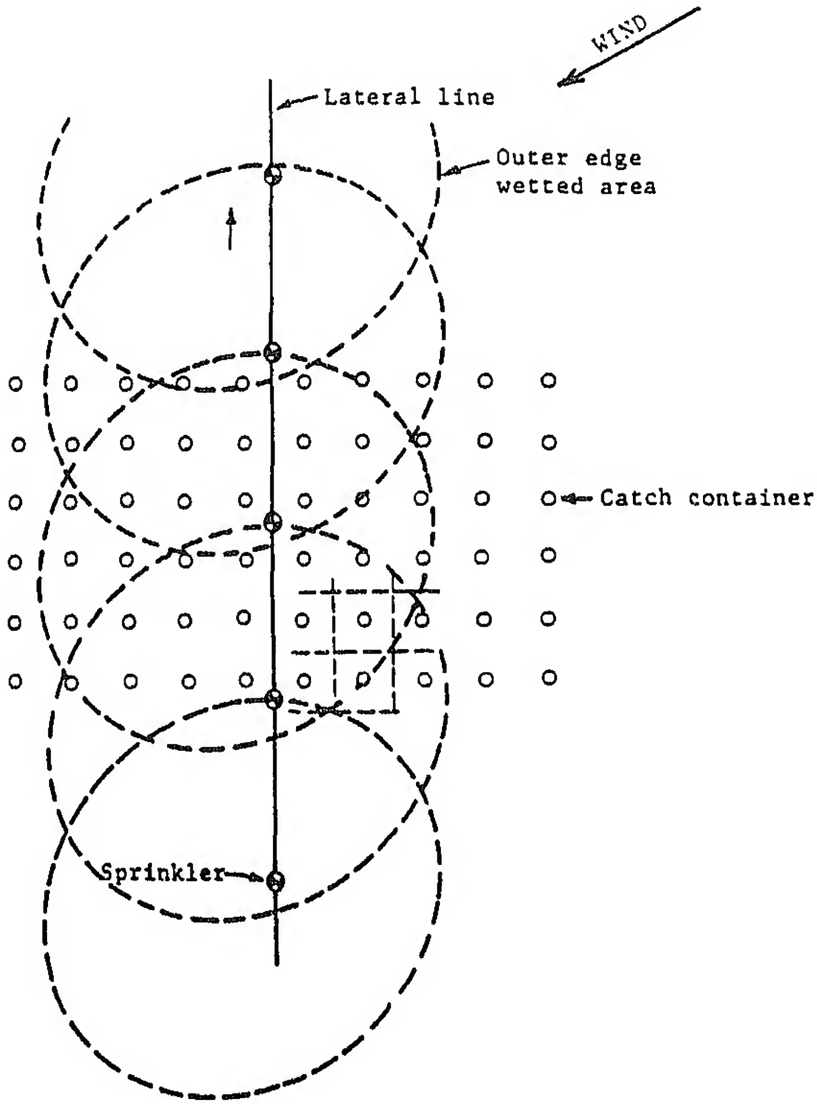
Figure C0687.8 - Loss of pressure due to friction along a lateral having only one size of pipe.

(ii) Set out at least 24 catch containers (see pattern in Figure C0687.9) on a grid having a spacing not to exceed 10- by 10-feet for testing along a single lateral line.

(a) The catch containers' pattern should be laid out to cover two adjacent areas between three sprinklers since sprinklers may not apply water at precisely uniform rates. Each catch container is assumed to give representative depth of catch over the square having the same dimensions as the can spacing in which it is centered. (See dotted grid lines in Figure C0687.9)

C0687.52(a)(3)(ii)(a)

Figure C0687.9 Layout of Catch Containers for Testing the Uniformity of Distribution Along a Sprinkler Lateral Line (both sides of a set)



(b) For solid set or block-move systems where several adjacent laterals operate simultaneously, the catch containers should be placed in the area between two adjacent laterals. Caution should be exercised to allow for any water that could enter the test container area from adjacent blocks.

(c) Each container should be located within a foot of its correct grid position and set carefully in an upright position with its top parallel to the ground; any surrounding vegetation that can interfere with a container, should be removed. When it is windy, they may be set in shallow holes. The most accurate means for measuring the catch can be achieved volumetrically by using a graduated cylinder. These measurements can be converted to depths if the area of the container opening is known. For 1-quart oil cans, 200 ml corresponds to 1.00 in depth. Other suitable catch containers may be square or cylindrical plastic freezer containers with sides tapered slightly for nesting or any similar container.

(d) Determine and record the container grid spacing and the ratio of volume to depth of catch. Also, indicate the position of the lateral and record the location and position numbers of the sprinklers on the lateral.

(iii) Determine the soil texture profile and management allowed deficit (MAD), then estimate the available soil moisture capacity in the root zone (see Measuring Soil Water Content Section) and check the soil moisture deficit, SMD, in the catch area on the side of the lateral that was not irrigated during the previous set. These values should be recorded as shown on lines 2 and 3 of Exhibit C0687.72.

(iv) Check and record the make and model of the sprinkler and the diameter of the nozzles.

(v) Obtain the normal sprinkler spacing and the duration and frequency of irrigation from the operator and record them. The standard way of expressing the sprinkler grid spacing is ________- by ________ -feet; this indicates the sprinkler spacing along the lateral and spacing between laterals in that order.

(vi) Read and record the rated sprinkler discharge, pressure, computed average design application rate from the system design data and manufacturer's sprinkler catalogs.

(vii) Check and record the size and slope of the lateral pipe and the height and erectness of the risers.

C0687.52(a)(3)(viii)

(viii) Before starting the test, stop the rotation of the sprinklers at the test site to prevent water from entering the containers. A short piece of wire or stick wedged behind the swinging arm facilitates this. A golf tee works as a plug for most nozzles.

(a) Turn on the water to fill the lateral lines. When the test lateral is full, turn the pressure up slowly to observe the trajectory, breakup of drops, and effect of wind at different pressures. Then set the pressure at the value desired for the test.

(b) Measure and record the pressure at the sprinklers to be tested at several places along the line and at both ends to observe the differences in pressure.

(c) On line 8, record how long it takes each sprinkler in this test area to fill the large container of known volume. Do this by slipping the short length of hose over the sprinkler nozzle and collecting the flow in the container. To improve accuracy, measure the nozzle output several times and compute the average. (If the sprinkler has two nozzles, each can be measured separately with one hose.) Often the measured sprinkler discharge rate is greater than what the manufacturer specified at the given pressure. This generally occurs because sprinkler nozzles often wear during use and become enlarged. You can check nozzle erosion with a feeler gauge such as a drill bit that has the diameter specified for the nozzle.

(ix) Note the wind speed and direction and record in part 9 by drawing an arrow relative to the direction of water flow in the lateral. Record temperatures.

(x) Empty all catch containers before starting the test; start the test by releasing all sprinklers surrounding the test site so they are free to rotate and note the starting time on line 10.

(xi) Outside the catchment area, set a container holding the anticipated amount of catch to check the approximate volume of water lost by evaporation (see Exhibit C0687.72, line 11).

(xii) While the test is in progress, check sprinkler pressures at 20 to 40 systematically selected locations throughout the system (for example at the two ends and quarter points along each lateral) and record the maximum, minimum, and average pressures encountered in part 12.

(xiii) Terminate the test by either stopping the sprinklers surrounding the test site in a position such that the jets do not fall into the containers, or by deflecting the jets to the ground. Note the time, check and record the pressure, and turn off the water. It is desirable for the test duration to be equal to the duration of an irrigation to get the full effect of wind and evaporation. Ideally, minimum duration tests should apply an average of about 0.5 inch of water in the containers.

(a) Measure the depth of water in all the containers and observe whether they are still upright; note any abnormally low or high catches. For long runs, where maximum depths exceed 2.0 inches, a measuring stick provides suitable accuracy up to +0.1 inch. As shown in part 10, caught depths or volumes are recorded above the line at the proper grid point, which is located relative to the sprinkler and direction of flow in the pipe line.

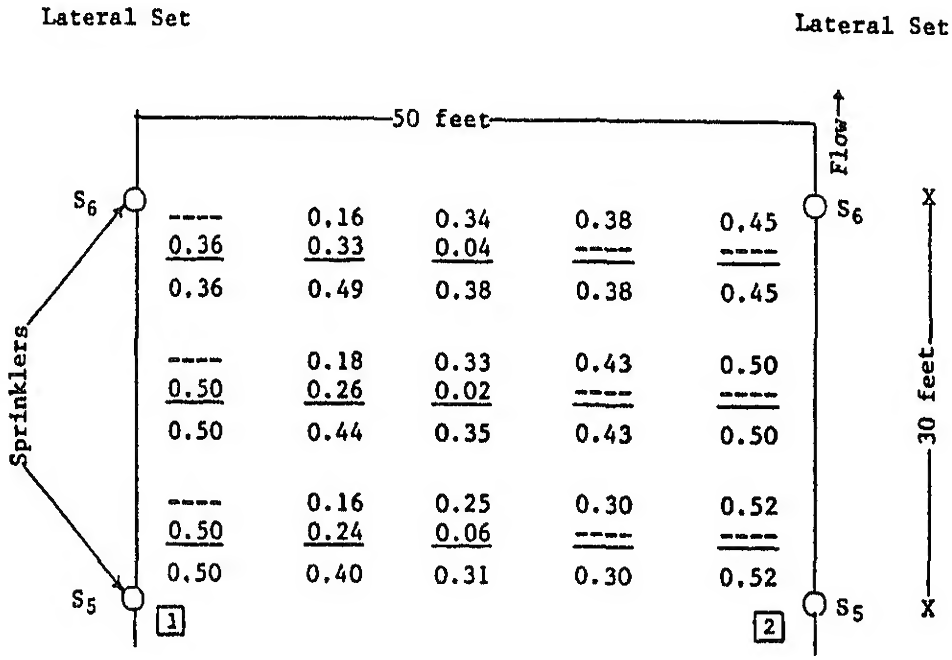
(4) <u>Utilization of field data.</u> The general procedure for utilizing the data is:

(i) Convert the volumes of water caught in the containers to depths and record them similar to Figure C0687.10. Assuming that the test is representative and that the next set would give identical results, the right-hand side of the catch pattern may, as if it were a subsequent set, be overlapped (or superimposed) on the left-hand side to simulate different lateral spacing. For lateral spacings that are whole units of the container spacings, the summation of the catches of the two sets represents a complete irrigation (Figure C0687.10 illustrates overlapping). For very close lateral spacings, water may overlap from as many as four lateral positions. Overlapping is not suggested where winds are likely to change appreciable between subsequent lateral sets. It is most valid for 24-hour sets.

(ii) To determine whether sprinklers are operating at acceptable efficiency, the system DU and CU should be evaluated. The system DU is based on the average depth recorded for the lowest one-fourth of the catch locations; hence, about 1/8 of the area may actually have received slightly less water. If an individual low value was due to a poor field measurement, perhaps no area actually received less. If the average low quarter depth infiltrated just matches the SMD the percent of the infiltrated water going too deep would be approximately equal to 100 - system DU. (A similar relationship exists for CU.)

C0687.52(a)(4)(ii)

Figure C0687.10 - Combined Catch Pattern (inches) Between Sprinklers 5 and 6 for a 50-foot Lateral Spacing



(iii) The potential system application efficiency, E_q and E_h, should be determined in order to evaluate how effectively the system can utilize the water supply and what the total losses may be. The total amount of water required to irrigate the field fully can be estimated.

(a) The E_q and E_h values are always a little lower than the DU and CU values of a sprinkler irrigation system because the average water applied is greater than the average water caught. The difference between the average water applied and the water caught and received is an approximation of losses due to evaporation and drift plus loss of water due to some of the area's being ungauged and some evaporation from the gauge cans. The system E_q and E_h indicate how well the tested sprinklers are able to operate if they are run the correct length of time to satisfy the SMD or MAD.

It is, therefore, a measure of the best management can do and should be thought of as the potential of the system within the limit that the test represents the whole field. The effective portion of applied water, Re, can be determined from the field data by:

$$Re = \frac{\text{average catch rate (or depth)}}{\text{application rate (or depth)}}$$

$$= \frac{\text{average catch rate}}{96.3\ q/(S_l \times S_m)}.$$

where

q = average sprinkler discharge rate, gpm

S_l = sprinkler spacing on the lateral, ft

S_m = lateral spacing along the main, ft

C0687.53 Traveling sprinklers.

(a) The following procedures are designed to check the uniformity and efficiency of irrigation across the travel paths. However, the nature of the operation and the large size of the sprinklers tend to reduce the quality of irrigation around field boundaries. It is particularly difficult to obtain high-quality irrigation at the ends of the towpath unless special control systems are used on the sprinkler. On small fields this is an appreciable area--as much as 200 feet on each end. If the traveling unit is powered by a water piston, the expelled water should not be included in evaluating the DU but should be included in computing the E_q and E_h.

(1) DU - "Distribution Uniformity" indicates the uniformity of infiltration (or application in the case of sprinkler or trickle irrigation) throughout the field and is expressed as a percent relating the average depth infiltrated in the lowest one-quarter of the area to the average depth of water infiltrated.

(2) E_q - "Application Efficiency of Low Quarter" indicates the actual efficiency being achieved with a given system and is expressed as a percent relating the average low quarter depth of water stored in the root zone to the average depth of water infiltrated.

(3) E_h - "Potential Application Efficiency of Low Quarter" is the measure of how well a system can perform under reasonably good management when the desired irrigation is being applied and is expressed as a percent relating the average low quarter depth infiltrated, when equal to MAD, to the average depth of water applied.

(b) Information required. The following information is required for evaluating travel sprinkler irrigation systems:

(1) Frequency of normal irrigations.

(2) MAD and SMD.

(3) Nozzle diameter and type for estimating systems' flow rate.

(4) Pressure at the nozzle.

(5) Depth of water caught in catch containers.

(6) Travel speed when the unit is at the test location and extreme ends of the towpaths.

(7) Spacing between towpaths.

(8) Rate of discharge from water piston (if applicable).

(9) Additional data indicated on Exhibit C0687.74.

An accurate estimate for the flow rate from the nozzle is necessary for calculating the E_h and E_q of the system. A good way to estimate this flow is to use the sprinkler performance chart provided by the manufacturer. A typical performance chart gives the rate of sprinkler discharge and diameter of coverage for various nozzle sizes at different pressures.

(c) Equipment needed.

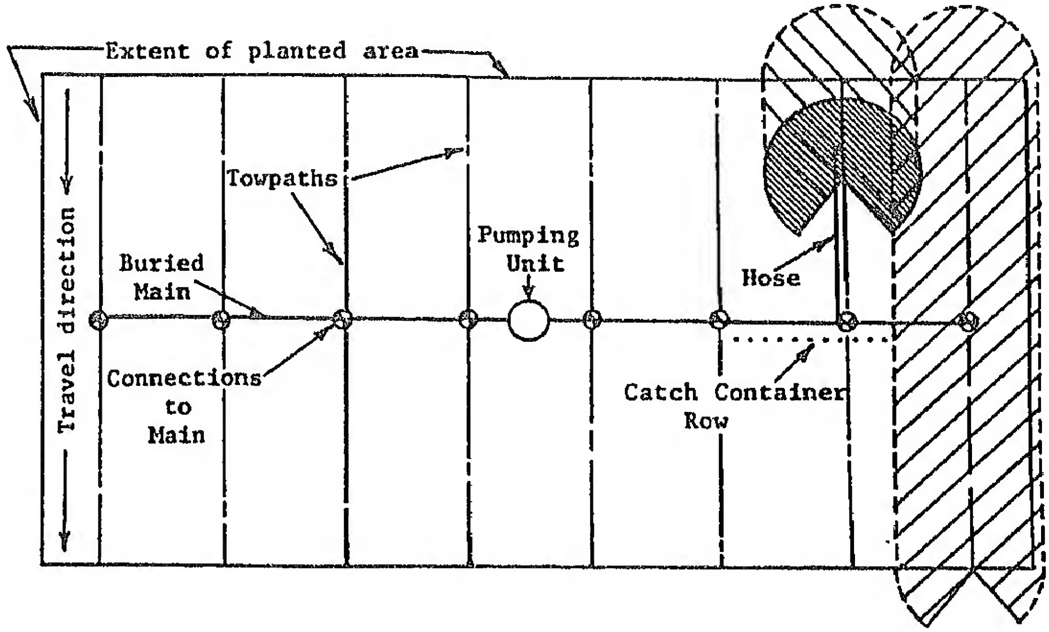
(1) A pressure gauge (0-150 psi) with pitot tube attachment.

(2) A stopwatch or watch with an easily-visible second hand.

(3) Approximately 60 catch containers such as 1-quart oil cans, plastic freezer cartons, plastic cups, or small rain gauges.

(4) A 250-ml graduated cylinder to measure volume of water caught in the containers.

Figure C0687.11 - Typical Layout for Traveling Sprinklers Showing Location of Catch Container Line for Evaluating the Distribution Uniformity



(5) A 50- or 100-foot tape for measuring distances in laying out the lines of containers and estimating machine's speed.

(6) A soil probe or auger.

(7) Manufacturer's sprinkler performance chart giving th relationship between discharge pressure, and wetted diameter p recommended operating pressure range.

(8) Speed specifications and setting instructions for th traveling vehicle.

(9) A shovel for smoothing areas to set catch containers and for checking profiles of soil, root, and water penetration

(10) A hand level to check differences in elevation.

(11) Exhibit CO687.74 for recording data.

(12) For travelers powered by a water piston, a 2- to 5-gallon bucket and possibly a short length of flexible hose to facilitate measuring the piston discharge.

(d) Field procedure. Fill in the data blanks of Exhibit CO687.74 during the field procedure process. Choose a test location about midway along the towpath where the traveler operates. The location should be far enough ahead of the sprinkler so no water reaches the test area before the catch containers are set up. It should be far enough from, the outer end of the path so that the back (or trailing) edge of the sprinkler pattern passes completely over it before the sprinkler reaches the end of the towpath. A good location for the test area is along the main line where an access road is usually provided. In tall-growing crops such as corn, an access road is the only practical location for the test.

(1) Set out a row of catch containers 10 feet apart across the towpath (see Figure Exhibit CO687.11); the containers that are adjacent to the towpath should be set on both sides of the towpath about 5 feet from the center of the path. The outer containers should be at the edges of the wetted strip. It is good practice to provide at least two extra containers on both ends of the container row to allow for changes in wind direction or speed.

(2) Fill in the data blanks about the crop and soil (lines 2 and 3 of Exhibit CO687.74).

(3) Check the SMD at the following locations: 10 feet from the towpath; one-fourth of the distance to the next towpath; and midway between the towpath in use and the one to be used next. Enter these SMD data in line 4.

(4) Note the make and model of the traveler, the sprinkler, type of nozzle (orifice ring or taper bore), and nozzle diameter. (It is also good practice to measure the nozzle size after the system is turned off. This is done to check for nozzle erosion so the estimated flow rate can be adjusted if necessary.) Enter this information in lines 5 and 6.

(5) Check the hose length and diameter and also the inlet and outlet pressures of the hose, if feasible. Record on line 7.

(6) Check and record on line 8 the type of drive used in the traveler. In evaluating water-piston powered travelers to estimate the drive flow, determine how long it takes the discharge from the piston to fill the bucket (or jug) of known volume.

(7) Measure and record the spacing between towpaths and the towpath length and general slope on line 9.

(8) Set out two containers with the anticipated catch to check the volume of evaporation losses. The first container should be set out when the wetted pattern first reaches the catch row and the second container when the sprinkler vehicle reaches the row. Record these catches on line 10.

(9) Determine the travel speed of the unit (ft/min) as it passes over the row of containers. This speed should also be checked at the extreme ends (beginning and terminal on Exhibit C0687.74) of the towpath and recorded on line 11. Stake out a known length, say 10 feet, and determine the time required for a point on the vehicle to travel between the stakes. An alternate method is to determine the distance traveled in a given time.

(10) Check and record in line 6 the pressure at the sprinkler nozzle when it is directly over the catch row and estimate the sprinkler discharge from the manufacturer's performance chart.

(11) Estimate and record in line 12 the total discharge from the traveler by adding the sprinkler nozzle and piston discharges. Also estimate and record the total pressure loss through the hose and sprinkler.

(12) Note in line 17 the general test conditions, i.e.: wind, speed and direction, angle degrees of the dry wedge of part-circle sprinkler operation, wet or dry spots, and runoff problems.

(13) Measure and record in line 17 the depth of water in all the containers as soon as possible and observe whether they are still upright; note any abnormally low or high catches. Measure and record in line 10 the catch in the two evaporation check containers after the last container in the row has been recorded.

(14) Note any special comments such as runoff, test problems, and crop water stresses in line 16.

(15) Do the computation work required on lines 17 and 13 through 15 of Exhibit C0687.74. Part 17 of Exhibit C0687.74 is designed to simplify the procedure of overlapping the catches to simulate a complete irrigation between adjacent towpaths. To use the form, number the containers from the towpath outward beginning with 1, 2, 3, etc., to the right and to the left looking opposite to the direction of travel. Enter the container numbers and catch volumes as follows: for the left side data start numbering with container one (1) opposite the actual towpath spacing (which for the example field evaluation is 330 feet) and number downward; and for the right side data start the numbering with container one (1) opposite the towpath spacing of 10 feet and number upward.

(e) Utilization of field data.

Data used in computations in Exhibit C0687.75 were recorded in evaluation of a traveling sprinkler system in a corn field. Assuming the test is representative and that the next run would give identical results, the left-hand side of the container catch volumes may be overlapped on (added to) the right-hand side. (see Figure C0687.11). Exhibit C0687.75 is designed to simplify this operation. The overlapped data totals provide an estimate of the profile of the depth of irrigation water between adjacent towpaths. For computation of DU, E_h, and E_q that follow, it is assumed that this depth profile represents the distribution throughout the field. In other words, the assumption is that the depth profile across the strip between towpaths is the same along the entire strip. This is obviously subject to question because of discontinuities at the path ends, changes in travel speeds, variations in pressure due to elevation, and changes in wind speed and direction.

(f) Distribution uniformity.

(1) In order to determine whether the system is operating at an acceptable and economical efficiency, the DU should be evaluated. For the sample test using the average and low one-quarter catch data from line 15 of Exhibit C0687.75:

$$DU = \frac{1.61}{2.27} \times 100 = 71 \text{ percent}$$

This is a fair value for a traveler system with widely-spaced towpaths and is generally independent of the speed of travel.

(2) It is useful to plot the depth of a catch along the distance between towpaths as a means for spotting problem areas. Note that the plotted points represent the depth of catch at the midpoint of each 10-foot interval between adjacent towpaths. Figure C0687.12 shows that either the towpaths are too far apart, which results in a shallow wetted depth midway between towpaths, or that the angle of the part circle is set too narrow. The effect of narrowing the spacing between towpaths can be measured by using a blank copy of Exhibit C0687.74, line 17, and repeating the above procedure with the same catch data and the new spacing. Widening this angle of the dry wedge would reduce the depth of water applied near the paths and would increase the depth of water applied midway between towpaths; but to measure the effect of widening the angle requires another catch test run.

(3) The check of travel speed shows that the unit moves faster toward the terminal end of the towpath run (See Exhibit C0867.75, line 11). This change in speed is caused by the interaction of the buildup of cable on the winch reel and the increased drag exerted by the hose as the unit moves from the beginning to the terminal end of the towpath. Fortunately, these two factors somewhat offset each other, and in the operation reported here the unit was traveling only 2 percent faster at the terminal end than in the test area and 5 percent slower at the beginning end (See Figure C0687.11.). These changes of speed would lower the DU over the entire strip by about three-eights of the total percent speed change, i.e., 3/8 x (2 + 5) or less than 3 percent.

(4) Since the nozzle pressure Is normally near 100 psi, differences in elevation are usually not great enough to affect DU appreciably. Only differences in elevation along the towpaths are of concern because valves can adjust hose inlet pressures. Even with a difference of 40 to 50 feet in elevation along the towpath, the DU decreases by only about 40 percent.

(5) Changes in wind speed and/or direction can greatly affect DU, especially if the wind direction changes appreciably during the operation in adjacent towpaths (blows from left in Figure C0687.11 one day and from the right the next day.) However, if the system is managed to operate approximately 24 hours in each towpath, as in the example test, wind problems are minimized. The traveler is set in about the same relative position along the adjacent towpaths at a given time of the day, when wind speed and direction are most likely to be similar.

C0687.53(g)

(g) Potential application efficiency (E_h) should be determined in order to evaluate how effectively the system can utilize the water supply and what the water losses may be. Then the total amount of water required to irrigate the field can be estimated. E_h is calculated from the ratio of the average low-quarter depth caught in the containers to the average depth applied. The average depth applied, d (in inches), is calculated from a constant times the total traveler discharge (the sprinkler discharge plus the piston discharge, if the traveler is driven by water piston) divided by the towpath spacing and the sprinkler's travel speed.

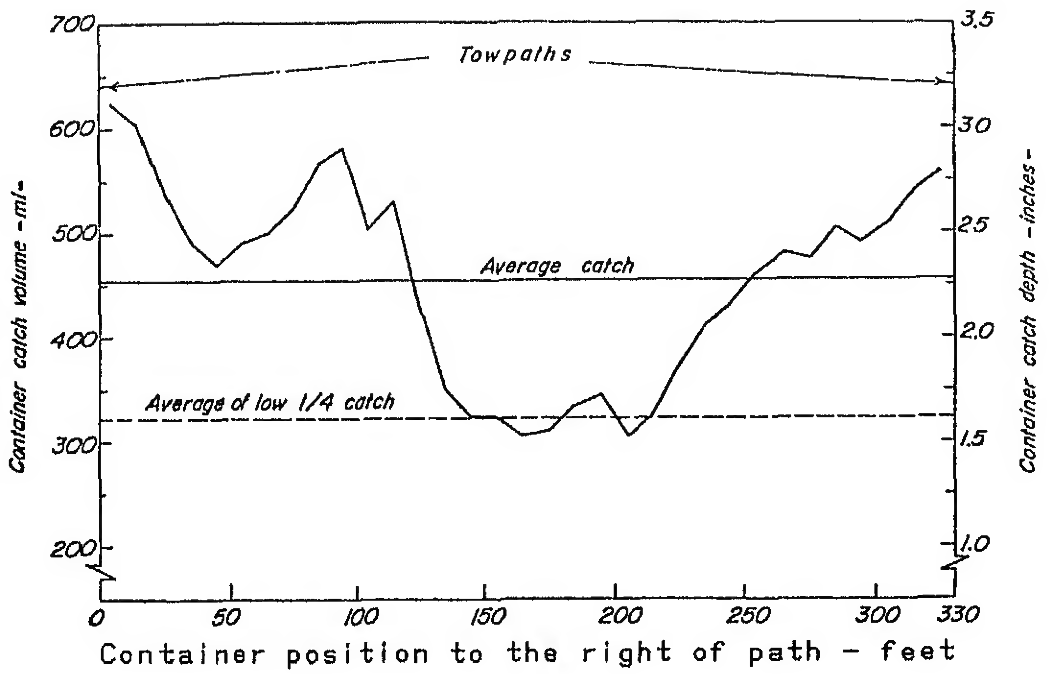
$$d = \frac{96.3}{60} \times \frac{\text{sprinkler plus piston discharge (gpm)}}{\text{path spacing (feet)} \times \text{travel (feet/min)}}$$

(1) From the sample data given on lines 9, 10, and 11, and computed on line 14 in Exhibit C0687.75, the average depth applied is 2.43 inches. The E_h with a low one-quarter depth of 1.61 inches is:

$$E_h = \frac{1.61 \times 100}{2.43} = 66 \text{ percent}$$

(2) This is a reasonable value for the central portion of a traveler irrigated field with such wide towpath spacings; however, the E_h around the boundaries will be much lower.

Figure C0687.12 - Profile of Overlapped Container Catch Data From Traveling Sprinkler Evaluation



(h) Application efficiency. Effectiveness of the use of the traveler system can be estimated by how much of the applied water is stored in the soil and available for consumptive use and by comparing the E_q and the E_h. The fine sandy loam soils in the area tested hold about 1.5 inches per foot available moisture. Depth of the root zone of the corn was 4.0 feet at that time, and a 35 percent MAD was considered ideal. This gives a MAD of 2.1 inches. The field checks showed that SMD near the towpath and at the 1/4 point were 2.1 inches and 2.2 inches, respectively, while in the middle of the strip it was 3.7 inches. The minimum depth of 1.6 inches was applied in the middle of the strip where the SMD was 3.7 inches (Figure C0687.11 and C0687.12). Thus, the system did not apply a full irrigation; no water was lost to deep percolation in the low-quarter application area and $E_q = E_h = 66$ percent. Apparently, much of the area had been receiving adequate irrigation because the SMD and MAD over much of the strip were less than or equal to the depth of application. Under-irrigation has created a cumulative deficit in the middle areas between towpaths.

(i) Application rate. The gun sprinklers, normally used on travelers can produce a rather flat pattern of distribution. That is, if the vehicle were standing still, the application depth or application rate over most of the wetted area would be fairly uniform. An estimate of the average application rate, (I) in inches per hour, can be obtained from a conversion constant times the flow (in gpm) from the sprinkler divided by the wetted area. The wetted area depends on the angle of the wet sector (for part-circle sprinklers).

$$I = \frac{96.3 \times \text{sprinkler discharge (gpm)} \times 360}{(\text{towpath spacing-feet})^2 \times \text{wet sector (degrees)}}$$

(1) For the sample evaluation (Exhibit C0687.75, lines 6 and 9), the sprinkler discharges 500 gpm and the towpath spacing is 330 feet with the part-circle sprinklers set for 15^0 dry sector, i.e., 345^0 wet. The estimated average application rate computed in line 13 is I = 0.46 in/hr. This is a fairly high application rate for the fine sandy loam soils which could cause infiltration and runoff problems in steeper areas or where the soil is in poor condition (tilth).

(j) Analysis and recommendations. Many of the observations and some recommendations that can be made from the data on Exhibit C0687.75, plus the DU and E_h computations, have already been referred to in other sections about

(1) <u>Operational checks.</u>
nozzle is ideal for good breaku
loss of 37 psi (10 psi in the d
inch by 660-foot flexible hose)
and 12.).

(2) <u>Runoff.</u> Infiltration did not appear to be a problem. The fine sandy loam soils could receive the light application at 0.46 iph with no runoff and the towpath remained relatively dry.

(3) <u>Improvements.</u> The only improvement necessary is to increase the DU. However, it is not reasonable to narrow the towpath spacing during the growing season. If this spacing is reduced, the number of towpaths and consequently the number of days between irrigations need not be increased. Several practical possibilities for improving the DU might be:

(i) Increase the angle of the dry area up to between 90° and 120°.

(ii) Try a taper bore nozzle, which would have a greater range for the same discharge and pressure.

(iii) Increase the nozzle to the next larger size.

(iv) Reduce towpath widths before next season.

(4) <u>Edge effects.</u> The outside towpaths of the present system are placed 150 feet inside the field boundaries. The field was laid out similarly to Figure CO687.11. There were 8 towpaths across the 2,610-foot width of the field--2,640 feet less a 30-foot road right-of-way. Data on Exhibit CO687.75 line 17, indicate this layout should give reasonable application (1.7 inches) on the downwind side but a very light (0.4 inch) watering along the upwind side. The traveler started at one end of the field and stopped at the opposite edge. This resulted in considerable overthrow by watering the ends of the field (Figure CO687.11) fairly well. The full length of the 660-foot hose was needed because it had to be dragged through the 1,320-foot length of the towpaths. The E_h of 66 percent computed earlier was for the central portion of the field; however, because of poor uniformity along the boundaries where there is insufficient overlap, plus water that is thrown outside of the planted area, the overall field efficiency is considerably lower. For the 80-acre field evaluated, the overall field E_h was estimated to be 52 percent. Much of this reduction in efficiency is due to poor uniformity along the edge of the field where the traveler is started and the edge where it stops. To minimize the decrease in E_h along the ends of the towpaths, the traveler needs to be started about 150 feet outside the edge of the field and allowed to travel 100 feet past the opposite edge of the field; these distances are unequal because of the wind. If the field were square (160 acre) with towpaths twice as long (2,640 feet), the relative end effects would be half as great and the overall field E_h would be approximately 57 percent.

(k) Summary. The DU of 71 percent and the E_h of 66 percent found in the evaluation are typical for performance of supplemental irrigation systems used on corn. The main problems in this system are associated with poor DU, in which the dryest part of the pattern occurred in the mid-portions of the strips between towpaths. Changing angle of the dry area of the sprinkler or the type or size of the sprinkler nozzle may improve the DU. Special control systems which essentially eliminate the reduction in E_h caused by the poor uniformity along towpath ends are in the pilot operation stage. These control systems change the angle of the part circle sprinkler and the speed of travel upon leaving and approaching the towpath ends. For the 80 acre field evaluated, such a control system could increase the overall field E_h by 10 percent or up to approximately 62 percent.

C0687.54 Furrow irrigation evaluation.

(a) The purposes for making an evaluation of a furrow or corrugation irrigation system are:

(1) To aid in assigning a named soil or group of soils to the proper furrow intake family (I_f) for design purposes.

(2) To determine the adequacy of the design criteria when irrigated under the specific field conditions existing on an individual farm.

(3) To provide recommendations for improving irrigation water management.

(b) Identification of the furrow intake family associated with a soil series or phase, for placement into irrigation guides, may require evaluations on only a few representative sites in an area.

(c) Inflow and outflow measurements representing an entire irrigation set are most desirable when making an evaluation for the purpose of placing a soil in a furrow intake family (I_f). An alternative is to measure inflow and outflow for the last one-fourth to one-half of the total irrigating time. When all irrigations during the season cannot be measured, it is desirable to make the furrow intake evaluations during the middle of the irrigation season. This represents average condition intake rates occur in the early part of the irrigat lower rates toward the end of the season.

(d) The following guidelines should be observed in conducting ·ow irrigation evaluations:

(1) Site selection. Furrow tests must be made on carefully ·cted sites representative of the soil being evaluated. The · should have no recognizable difference in soils throughout length that is to be evaluated. The furrows should have a ·orm cross-section and uniform grade between the inflow and flow measuring points. Wheel rows should not be evaluated; ·ver, they may be included when evaluating a group of furrows.

(2) Soil moisture. Onsite estimates of soil moisture uld be made when evaluating a specific field. Where feasible, dies should be made when moisture conditions indicate that a mal irrigation application is needed.

(3) Cropping history. The present crop, stage of growth previous crop should be recorded.

(4) Soil conditions. The condition of the furrow (freshly tivated, cloddy, dispersed soil, smoothed by previous igation, etc.) has a marked influence on furrow intake rate should be recorded. The number of times the field has been igated since the start of the irrigation season, and since the t furrowing operation, should also be known.

(5) Flow measurements. The flow of water in furrows can be ısured in several ways. Inflow can be measured volumetrically, ·h a calibrated container and stopwatch, where the flows are ll (up to about 20 gpm) or with a number of small measuring ·ices (e.g., orifice plates, V-notch weirs, trapezoidal flumes, .). Outflow can be measured with any of the above small ısuring devices. See NEH Section 15, Chapter 9, "Measurement Irrigation Water," for additional information. Care should be .en in the selection and installation of the measuring devices, as not to block the furrow flow. The outflow measuring device ›uld be located at a point where backwater does not affect the w.

(6) Flow control. The flow rate should be constant ·oughout the test. If the inflow rate changes, the volume of :er in channel storage in the furrow also changes. This change channel storage must be measured in order to determine how :h of the flow is going into the soil as intake.

(7) Installation. At least three adjacent furrows or furrow groups should be measured on each test site. Adjacent furrows on each side of the test area should also be irrigated simultaneously.

(e) Procedure.

(1) The furrow length between the inflow and outflow measuring stations should be measured and not estimated. Normally, the full furrow length should be evaluated. The minimum evaluation length should be 200 to 300 feet for high intake rate soils, and 500 to 600 feet for low intake rate soils. The average furrow slope and cross-section need to be determined. Readings should be taken to determine uniformity of grade. It is desirable to use the same flow rate that the farmer normally uses as part of the evaluation, even if the flow rate results in erosion. The minimum flow should be large enough to produce a fairly uniform rate of advance. Record the time water starts flowing in each furrow.

(2) Adjust streams so that flows into all furrows are approximately equal. Periodically measure the inflow stream. Record the time when water starts to flow through the outflow measuring device. Periodically measure and record the outflow stream. When ending the intake evaluation before completion of the full irrigation, take final inflow-outflow measurements at the same time and measure the depth of flow in the furrows.

(3) Though not needed for the evaluation, it is desirable to measure the wetted bulb about 24 hours after the completed irrigation to determine the wetting pattern. For these measurements, a soil moisture probe will readily define the boundary line between the wet soil and relatively dry soil. The opportunity time to obtain this wetted pattern should be included with the sketch of the bulbs. Another method which can be used is to excavate a trench perpendicular across the furrow and observe the wetted area.

(f) Computation and evaluation.

(1) For each furrow or group of furrows, determine the average inflow (Q_1), the inflow time (T_1), the average outflow (Q_2), the outflow time (T_2), and the cumulated volumes of inflow (V_{in}) and outflow (V_{out}) at the end of the irrigation and at selected intermediate times. The minimum selected intermediate time should be such that flow has reached the outflow station, flow is reasonably uniform, and su[illegible]
furrow reach is stable. For ea[illegible]
three points in order to plot c[illegible]
Each point is described by the

C0687.54(g)(2)(i)

(2) plotting points

$$T_0 = 0.5 \times 60 \text{ min/hr (inflow time (hrs) - outflow time (hrs))}$$

$$aT_0^b + c = \frac{1.6041}{\text{Length} \times P} \text{ (inflow (gal) - outflow (gal) - surface storage (gal))}$$

(i) intake at 1701 hours (17.0)

$$T_0 = 0.5 \times 60 \, ((16.5 - 8.5) + (17.0 - 11.0)) = 420 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (6764.0 - 3060 - 0) = 4.49 \text{ inches}$$

(ii) intake at 1430 hours (14.5)

$$T_0 = 0.5 \times 60 \, ((14.5 - 8.5) + (14.5 - 11.0)) = 285 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (5090 - 1771 - 500) = 3.42 \text{ inches}$$

(iii) intake at 1330 hours (13.5)

$$T_0 = 0.5 \times 60 \, ((13.5 - 8.5) + (13.5 - 11.0)) = 225 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (4235 - 1212 - 500) = 3.06 \text{ inches}$$

(iv) intake at 1230 hours (12.5)

$$T_0 = 0.5 \times 60 \, ((12.5 - 8.5) + (12.5 - 11.0)) = 165 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (3380 - 666 - 500) = 2.68 \text{ inches}$$

(v) Additional points are similarly derived are:

T_o = 50 min, F = 1.35 in.
T_o = 100 min, F = 1.99 in.
T_o = 600 min, F = 5.33 in.

(3) Plot the data points derived for cumulative intake vs. opportunity time, see Figure C0687.14.

(iii) The average opportunity time (T_0), in minutes, may be determined as the average of the inflow time (T_1) and the outflow time (T_2):

$$T_0 = 0.5\ (T_1 + T_2)$$

(3) When the advance is curvilinear, a more exact value of average opportunity time can be obtained by averaging the opportunity time at various points along the furrow length, or by integration of the advance curve.

(4) Computation of the opportunity time is facilitated by converting the 24-hour clock time used to record the time of measurements, to decimal hours. For example, the 24-hour clock time of 1120 would become 11.33 (11 + (20 divided by 60)).

(5) A plot of cumulated inflow and outflow in gallons vs. clock time since the start of irrigation facilitates determination of the intake volume at any elapsed time, when simultaneous measurements of flow are not made. Subtraction of the cumulated outflow from the cumulated inflow yields the intake and storage. Subtraction of the surface storage yields the volume of intake, in gallons, at any time.

(6) The cumulated intake ($F_{(0-L)}$) and associated opportunity time (T_0) points, when plotted on log-log paper, define the measured intake line. (See Figure C0687.14.) This line is then compared to standard intake family lines, Figure C0685.5 to determine the most representative intake family.

(g) Example. Determine furrow intake family from trial measurements where the total irrigation is measured (using data contained on Furrow Intake Data sheets, see Figure C0687.13. For brevity, only one furrow evaluation is illustrated

(1) given:

Soil: Las Animas fine sandy loam
$L = 900$ feet
$S = 0.003$ ft/ft

$W = 2.5$ feet
$Q_1 = 14.09$ gpm
$n = 0.04$

$$P = (0.2686)(14.09 \times .04/.003^{0.5})^{0.4247} + .75 = 1.47 \text{ feet}$$

$$V_s = 900\ [(.09731)(14.09 \times .04/.003^{0.5})^{0.7527} - .00574] = 500 \text{ gallons}$$

C0687.54(g)(2)(i)

(2) plotting points

$$T_0 = 0.5 \times 60 \text{ min/hr (inflow time (hrs) - outflow time (hrs))}$$

$$aT_0^b + c = \frac{1.6041}{\text{Length} \times P} \text{(inflow (gal) - outflow (gal) - surface storage (gal))}$$

(i) intake at 1701 hours (17.0)

$$T_0 = 0.5 \times 60 ((16.5 - 8.5) + (17.0 - 11.0)) = 420 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (6764.0 - 3060 - 0) = 4.49 \text{ inches}$$

(ii) intake at 1430 hours (14.5)

$$T_0 = 0.5 \times 60 ((14.5 - 8.5) + (14.5 - 11.0)) = 285 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (5090 - 1771 - 500) = 3.42 \text{ inches}$$

(iii) intake at 1330 hours (13.5)

$$T_0 = 0.5 \times 60 ((13.5 - 8.5) + (13.5 - 11.0)) = 225 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (4235 - 1212 - 500) = 3.06 \text{ inches}$$

(iv) intake at 1230 hours (12.5)

$$T_0 = 0.5 \times 60 ((12.5 - 8.5) + (12.5 - 11.0)) = 165 \text{ minutes}$$

$$aT_0^b + c = \frac{1.6041}{900 \times 1.47} (3380 - 666 - 500) = 2.68 \text{ inches}$$

(v) Additional points are similarly derived are:

T_0 = 50 min, F = 1.35 in.
T_0 = 100 min, F = 1.99 in.
T_0 = 600 min, F = 5.33 in.

(3) Plot the data points derived for cumulative intake vs. opportunity time, see Figure C0687.14.

(4) Find the closest intake family (I_f) number by comparing cumulative intake values read from the plotted date at 100, 200, 300, and 400 minutes with values in Figure C0687.15

Plotted Values		Tabular Values	
Time	F_n	F_n	I_f
100	1.99	1.97	0.6
200	2.9	2.75	0.5 or 0.6
300	3.7	3.62	0.5
400	4.3	4.43	0.5

Therefore, select 0.5 as the closest intake family derived from the field data.

(5) There are programs available for programmable calculators that can compute the intake family number directly from field trial data.

(6) Remember that intakes will vary during the season as well as from one field to another. The value should be used with discretion when reviewing alternatives derived from its use.

C0687.55

C0687.55 Example, furrow irrigation data sheet.

FURROW INTAKE DATA SHEET

Owner J. Walker SCD Fremont County Fremont

Legal Description ________________ Date 8/5/86 By: SBT

Soil Series-Mapped Las Animas FSL Actual lfs Slope 0.5%

Furrow Condition (Circle): Loose Slick (packed) (Firm)

Restrictive Layers: Surface Crusting - Yes____ No X
Tillage Pan - Yes X No____ Depth 8"
Other NONE Depth ________

Normal Set time 8 Hrs. Frequency 8 Days Ave. Stream 14 GPM

Soil Moisture (Before) Soil Moisture ____hrs (After)

35% 6" 50% 12" 70% 36" ____ 6" ____ 12" ____ 36"

Present Crop Corn Crop 85 Yr Potatoes Crop 84 Yr Wheat

Furrow Erosion:

Upper Third (Circle) Deposition None Slight Moderate (Severe)
Middle Third (Circle) Deposition None (Slight) Moderate Severe
Lower Third (Circle) (Deposition) None Slight Moderate Severe

Furrow Spacing (in.) 30 Irrigation Pattern (Adjacent)
Every ______ Furrow

Average Furrow Length 900 Stream Size to Field 700 gpm

Field Width 1000 ft Normal Seasonal Number of
Irrigations 14

Irrigation Number (Circle): 1st 2nd 3rd 4th 5th 6th 7th 8th 10th

Comments: (Such as crop condition, excessive wet areas, field grade, uniformity, etc.)

Crop appears uniform in growth except at tail end where it appears drowned out due to excessive tailwater. High amount of runoff occurring. Field grade very uniform.

Figure C0687.13 Sample Furrow Flow Data Set

Furrow Flow Data

Farm J. Walker SCD or SWCD Fremont Sheet 1 of 2 Date 4/5/78 By WC

Legal Description

Furrow No. 1 Station 0+00 Inflow X or Outflow

Measuring Device 1.5" Orifice free flow

(1) Clock* Time	(2) Elapsed Time (min)	(3) ΔT (min)	(4) Gage H ( )	(5) Flow Rate (gpm)	(6) Average Flow Rate (gpm)	(7) Volume (gal)	(8) Σ Volume (gal)	(9) Advance Time: Clock Time	(10) Advance Time: Elapsed Time (min)	(11) Advance Time: Station (ft)
0830	0			0				0841	11	2+00
0835	5	5		12.61	6.31	31.52	31.52	0857	27	4+00
0840	10	5		14.23	13.42	67.10	98.6	0914	44	5+00
0900	30	20		14.27	14.25	285.0	383.6	0932	62	6+00
1000	90	60		14.29	14.28	856.8	1240.4	0955	85	7+00
1100	150	60		14.25	14.27	856.2	2096.6	1024	114	8+00
1300	270	120		14.27	14.26	1711.2	3807.8	1100	150	9+00
1600	450	180		14.23	14.25	2565.0	6372.8			
1625	475	25		14.22	14.22	355.6	6728.4			
1630	480	5		0	7.11	35.6	6764.0			

$$Q_1 = \frac{6764}{480} = 14.09\ gpm$$

*24 hour clock time

Furrow Flow Data

Farm J Walker SCD or SWCD Fremont Sheet 2 of 2 Date 4/5/78 By WC

Legal Description

Furrow No. 1 Station 9+00 Inflow or Outflow X

Measuring Device

(1) Clock* Time	(2) Elapsed Time (min)	(3) ΔT (min)	(4) Gage H ( )	(5) Flow Rate (gpm)	(6) Average Flow Rate (gpm)	(7) Volume (gal)	(8) Σ Volume (gal)	(9) Advance Time: Clock Time	(10) Advance Time: Elapsed Time (min)	(11) Advance Time: Station (ft)
1100	0			0						
1110	10	10		4.28	2.14	21.4	21.4			
1130	30	20		8.36	6.32	126.4	147.8			
1230	90	60		8.90	8.63	517.8	665.6			
1330	150	60		9.30	9.10	546.0	1211.6			
1530	270	120		9.34	9.32	1118.4	2330.0			
1630	330	60		9.34	9.34	560.4	2890.4			
1640	340	10		7.93	8.64	86.4	2976.8			
1701	361	21		0	3.96	83.2	3060.0			

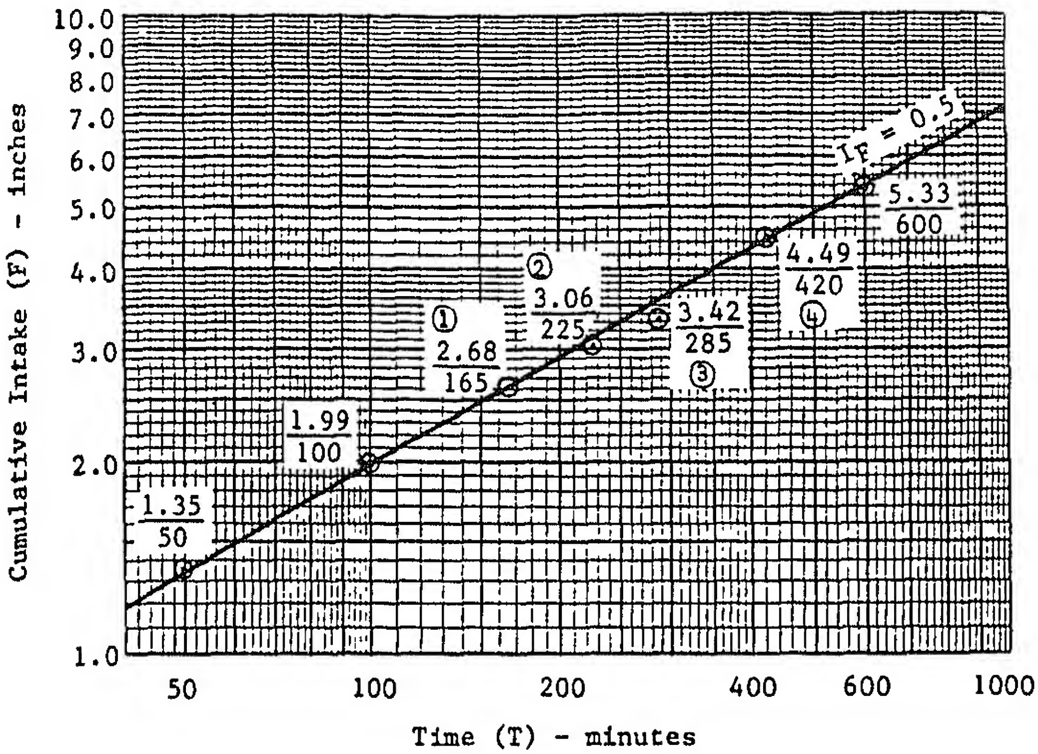
$$Q_2 = \frac{3060}{361} = 8.48\ gpm$$

*24 hour clock time

C0687.55

Figure C0687.14 Cumulative intake vs. time.

Example #1 - Entire Irrigation Measured



NOTE:

1. For line of best fit comparison, using family of curves, $I_f = 0.5$.

2. For linear regression analysis, $F = aT^b$, a = .1567,

   b = .5514, or $F = .1567T^{.5514}$ or $I_f = 0.42$.

3. For curvilinear regression analysis, using points 1 through 4, a line represented by the equation, $F = aT^b + c$ gives:

   $F = .00029T^{1.4941} + 2.097$ or $I_f = 0.61$

Figure C0687.15 Cumulative Intake Family (F_n) by Intake Family - Inches 1/

Intake Family	a 2/	b 2/	Opportunity Time (To) - minutes			
			100	200	300	400
0.10	0.0244	0.6610	0.79	1.08	1.33	1.56
0.15	0.0276	0.6834	0.92	1.31	1.64	1.93
0.20	0.0306	0.6988	1.04	1.52	1.92	2.29
0.25	0.0336	0.7107	1.16	1.73	2.21	2.65
0.30	0.0364	0.7204	1.28	1.93	2.49	3.00
0.35	0.0392	0.7285	1.40	2.14	2.77	3.36
0.40	0.0419	0.7356	1.51	2.34	3.06	3.71
0.45	0.0445	0.7419	1.63	2.54	3.34	4.07
0.50	0.0471	0.7475	1.75	2.75	3.62	4.43
0.60	0.0520	0.7572	1.97	3.15	4.18	5.13
0.70	0.0568	0.7656	2.20	3.56	4.75	5.85
0.80	0.0614	0.7728	2.43	3.96	5.32	6.57
0.90	0.0659	0.7792	2.66	4.37	5.89	7.30
1.00	0.0703	0.7850	2.89	4.78	6.46	8.03
1.50	0.0899	0.7990	3.84	6.47	8.84	11.06
2.00	0.1084	0.8080	4.75	8.11	11.15	14.00

1/ Fn = aTo^b + .275
2/ From Figure C0685.5

SUBPART E - INTAKE RATE AND MAXIMUM APPLICATION RATE MEASUREMENT PROCEDURES

C0687.60 Sprinkler - set type.

(a) Infiltration testing procedure.

(1) The procedure utilizes a portable trailer-mounted recirculating unit with a sprinkler head mounted within a circular shield. The test equipment was set up so the sprinkler threw with the wind. The sprinkler was run for one or two revolutions to mark the "fan" pattern from the sprinkler.

(2) Cans to measure application rates are set at five-foot intervals in groups of three down the center of the fan formed by the spray pattern. Care must be taken to avoid foot traffic in the area where the infiltration observations are to be made.

(3) If the soil moisture content is less than field capacity, the soil must be pre-irrigated with about 350 gallons of water to a minimum depth of 3 to 6 inches. The test is run about one hour after the conclusion of the pre-irrigation. If the "intake rate" drops during the "test" run, the run is considered a wetting operation and another run must be made for "test" purposes.

(4) The tests usually are run for one hour with observations taken every 15 minutes.

Under		Adequate		Over	
1	2	3	4	5	6

1 - Water infiltrated within 1/4 of the time required for the sprinkler spray to return to the point observed.

2 - Water infiltrated within 1/2 of the time required for the sprinkler spray to return to the point observed.

3 - Water infiltrated within 3/4 of the time required for the sprinkler spray to return to the point observed.

4 - Water infiltrated by the time the sprinkler spray returned to the point observed.

5 - Water was ponded at the surface when the sprinkler spray returned but no runoff has occurred.

6 - Water was ponded at the surface when the sprinkler spray returned and runoff is occuring.

C0687.60(a)(5)

(5) At the conclusion of the test, the can catchments are measured and converted to application rates expressed in inches per hour. Rating number 4, adequate, is the desired infiltration rate of the soil for each specific test. It is the maximum application rate that should be used with a sprinkler system on the type of soil tested.

(6) Figure C0687.15 aids in documenting this test.

(7) Comments as to wind condition and ground condition greatly aid in determining whether the test is an actual representation of the soil's sprinkler intake rate (iph).

(8) This test can be modified for sprinkler systems by replacing an existing head with one that has an adjustable pin to regulate width of throw or one that can be adjusted for a part circle.

C0687.61 Sprinkler - Pivot

The maximum application rate should be field checked on each system evaluated. From visual observations the area which appears to be the wettest should be checked. This is usually near the end tower.

(a) Place five catch cans (spaced about ten feet apart) in a line perpendicular to the sprinkler line. One can should be directly under the nozzle when timing is started, with two cans forward and two cans behind the first can. Cover the cans with plastic lids, small sheets of cardboard, wood or plastic bags.

(b) Remove covers (as quickly as possible) from all cans and start timing when nozzle is directly over center can. Observe intake characteristics of the soil throughout the test.

(c) After five or ten minutes operation, cover cans (as quickly as possible).

(d) Measure quantity caught. The can with the largest quantity will represent the average application rate for that time duration (5 or 10 minutes). This approximates the maximum rate when time of catch is this short.

Figure C0687.15 Soil intake rate test for sprinkler design.

Date ______________

Farm ______________ Soil Type ______________

Sprinkler Nozzle Size ______________ Pressure ______________

Test Started ________ Test Ended ________ Total Time ________ minutes

Distance from spr.	Can Catchment						Appli. Rate	Observed Intake Rate		
	Row 1	Row 2	Row 3	Total	Ave.	Adj. 1 hr.				
feet	cc.	cc.	cc.	cc.	cc.	cc.	"/hr.	1 2 under	3 4 adeq.	5 6 over
(1) 5										
(2) 10										
(3) 15										
(4) 20										
(5) 25										
(6) 30										
(7) 35										
(8) 40										
(9) 45										
(10) 50										
(11) 55										
(12) 60										
(13) 65										
(14) 70										

REMARKS:

Test Made by ______________

C0687.61(e)

(e) Compute rate:

$$\text{inches per hour} = \frac{(\qquad\qquad \text{ml})(60)}{(\text{can factor})(\text{Time, min.})\ (200)}$$

where 200 = standard size oil can factor

$$\text{or: inches per hour} = \frac{(\qquad \text{inches})(60)}{(\text{Time, in minutes})}$$

(f) This test needs to be duplicated at other locations along the pivot sprinkler line, in the same area to eliminate the effect of nozzle pattern on the application rate.

(g) Note: Catch can spacing will have to be modified on fast-moving, low-pressure systems.

(h) Further tests need to be made closer in toward the pivot to determine the maximum soil intake rate for that site if the test near the end tower does, in fact, show runoff. This point will not necessarily be easy to observe, until after some practice.

(i) Figure C0687.16 is a worksheet that will aid in completing this evaluation.

(j) Instructions for performing intake/application test:

(1) Select a field being irrigated in the normal manner by the farmer.

(2) After irrigation has progressed long enough so that the soil has reached its basic intake rate, usually toward the end of the irrigation period, locate areas in the field where the water is absorbed in the same length of time as it takes for the sprinkler head to revolve and again spray the area. <u>There should be no movement of water over the surface, and more than the slightest ponding is generally unsatisfactory.</u>

(3) <u>Non-Motion Equipment</u> (Wheel lines, Solidset, etc.)

(i) Parallel to the nozzles place five one-quart oil cans, with the tops removed, at the selected locations. On soils with little cover, dig the cans slightly into the ground to prevent overturning. Where heavy cover is present, mount the cans with heavy rubber bands on stakes so that they are just above the top of the cover.

(ii) Record the time, in hours and minutes, at which each can is placed in position.

Figure C0687.16 Sprinkler Intake/Application Rate Test

Owner________ CD________ County________

Legal Description________ Date__/__/__ By:________

Soil Series-Mapped________ Actual______ Land Slope________(Abney)

Field Condition (circle): Pulverized Fine Clods (marbles) Medium Clods (egg) Large Clods (baseball)

Surface Crusting - Yes__ No__ Tillage Plan - Yes__ No__ Depth________

Other Restrictive Layers: Kind________ Depth________

Subsoiled. Date__/__/__ Depth______ Spacing______ Direction______

Tillage Implement	Date	Implement	Date	Implement	Date

Pitter or Dam Master (Spacing)________ Other (describe)________

Previous Crop History:

19__ ______ crop ______ yield 19__ ______ crop ______ yield

19__ ______ crop ______ yield 19__ ______ crop ______ yield

Field Residue (circle): None 0-199 Low 200-499 Medium 500-799 High 800+

Present Crop________ Cropping Direction (circle): Contour Cross Slope Up & Down Slope

Cover Crop: Annual______ (type) /__% Prennial______ (type) /__%

Green Manure Incorporated: Date__/__/__ Tillage________

Crop Canopy (circle): 0 to 10% 11 to 25% 26 to 50% 51 to 75% 76 to 100%

Average Sheet & Rill
Erosion (check): None 0-2__ Slight 2-5__ Moderate 5-10__ Severe 10-20__ Very Severe 20+__

Concentrated Flow
Erosion (check): Wheel Tracks__ Draws__ (slight, moderate, severe)

Irrigation System (circle): Center pivot Wheel line Hand line Big Gun Solid set Other________

Can No.	Time			Volume of Water Caught (cc.)	Depth of Water Caught (Ins)	Intake Rate (Ins/Hr)
	Begin Test	End Test	Elapsed Time (Hrs)			
Average	X	X	X	X	X	

Comments:________

C0687.61(j)(3)(iii)

(iii) Not less than one hour later (a longer period is preferable) remove the cans and record the pertinent catch time for each can, in hours and minutes.

(iv) Measure, and record, the volume in cubic centimeters caught by each can. An inexpensive graduate for this purpose is an ordinary glass or plastic baby bottle calibrated in cubic centimeters.

(v) Compute and record the elapsed time for each can in hours to the nearest .01 hour. For example: 1 hour 45 minutes = 1.75 hours.

(4) Motion Equipment (Center pivots, Walking laterals, etc.)

(i) Place five catch cans (spaced about ten feet apart) in a line perpendicular to the sprinkler line. One can should be directly under the nozzle when timing is started. Place two cans forward and two cans behind the first can. Cover the cans with plastic lids, small sheets or cardboard, wood, or plastic bags.

(ii) Remove covers (as quickly as possible) from all cans and start timing when nozzle is directly over center can.

(iii) After five or ten minutes operation, cover cans (as quickly as possible).

(iv) Measure quantity caught. The can with the largest quantity will represent the maximum application rate.

(5) Convert the volume caught in cubic centimeters to depths caught in inches and record. An ordinary one quart oil can holds approximately 200 cc. per inch of depth so to make the conversion merely divide the volume caught in cc. by 200.

(6) The intake rate of the soil is computed by dividing the depth of water caught in inches by the elapsed time in hours.

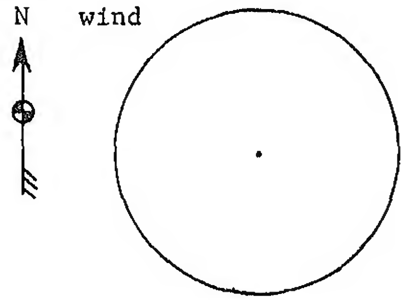
(7) Record comments.

C0687.62 Surface - Furrow or Corrugation

Determination of intake rates under this method of irrigation is directly tied to the evaluation procedure. Refer to Section C0687.54.

Exhibit C0687.70 Center Pivot Sprinkler Irrigation Evaluation Form

1. Location ____________, Observer _____, Date & Time ______________
2. Equipment: make _______, length _____ft, pipe diameter ______in
3. Drive: type _______ speed setting ____%, water distributed? _____
4. Irrigated area = $\frac{3.14\ (\text{wetted radius} \_\_\_\_\_\_\_\_\ \text{ft})^2}{43{,}560}$ = ______acres
5. N wind



*Mark position of lateral, direction of travel, elevation differences, wet or dry spots and wind direction.

Wind ____mph, Temperature ______°F

Pressure: at pivot __________psi

at nozzle end ______psi

Diameter of largest nozzle _____in

Comments: ________________

6. Crop: condition __________________________, root depth ______ft
7. Soil: texture ___________, tilth ______, avail. moisture ______in/ft
8. SMD: near pivot ______in, at 3/4 point _____in, at end _______in
9. Surface runoff conditions at 3/4 point ______, and at end _______
10. Speed of outer drive unit _____ft per _____min = __________ft/min
11. Time per revolution = $\frac{(\text{outer drive unit radius} \_\_\_\_\_\ \text{ft})}{9.55\ (\text{speed} \_\_\_\_\_\_\_\ \text{ft/min})}$ = ______hr
12. Outer end: water pattern width ______ft, watering time ______min
13. Discharge from end drive motor _____gal per ______min = ______gpm
14. System flow meter ____________gallons per ________min = ________gpm
15. Average weighted catches:

System = $\frac{(\text{sum all weighted catches} \_\_\_\_\_\_\_\_\_\_)}{(\text{sum all used position numbers} \_\_\_\_\_)}$ = ______ml = _____in

Low 1/4 = $\frac{(\text{sum low 1/4 weighted catches} \_\_\_\_\_\_\_\_\_\_)}{(\text{sum low 1/4 position numbers}}$ = _____ml = _____in

16. Minimum daily (average daily

$\frac{(\_\_\_\_\ \text{hrs operation/day}) \times (1}{(\_\_\_\_\_\ \text{hrs/rev}}$

17. Distribution Uniformity (DU) =

C0687.70

Exhibit C0687.70 Center Pivot Sprinkler Irrigation Evaluation Form

18. Container catch data in units of ______, Volume/depth ______ ml/in

Span length ______ ft, Container spacing ______ ft

Evaporation: initial ______ ml ______ ml

final ______ ml ______ ml

loss ______ ml ______ ml, ave ____ ml = ____ in

Span no.	Container Position Number	X Catch =	Weighted Catch	Span No.	Container Position Number	X Catch =	Weighted Catch
	1				37		
	2				38		
	3				39		
	4				40		
	5				41		
	6				42		
	7				43		
	8				44		
	9				45		
	10				46		
	11				47		
	12				48		
	13				49		
	14				50		
	15				51		
	16				52		
	17				53		
	18				54		
	19				55		
	20				56		
	21				57		
	22				58		
	23				59		
	24				60		
	25				61		
	26				62		
	27				63		
	28				64		
	29				65		
	30				66		
	31				67		
	32				68		
	33				69		
	34				70		
	35				71		
	36				72		

Sum all: used position numbers ________, weighted catches ____________

Sum low 1/4: position numbers ________, weighted catches ____________

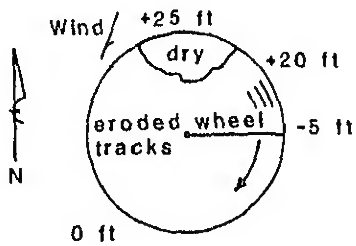
Exhibit C0687.71 Center Pivot Sprinkler Irrigation Evaluation Form

1. Location Akron, Observer JK, Date & Time 7/18/88 p.m.

2. Equipment: make HG 100, length 1375 ft, pipe diameter 6-5/8 in

3. Drive: type electric

4. Irrigated area = $\frac{3.14 \text{ (wetted radius } 1450 \text{ ft)}^2}{43,560}$ = 152 acres



*Mark position of lateral direction of travel, elevation differences, wet or dry spots and wind direction.

Wind 6 mph, Temperature 85 °F
Pressure: at pivot 86 psi
at end tower 60 psi
Diameter of largest nozzle 1/2 in
Comments: Sprinklers operating OK, but end part circle sprinklers out of adjustment.

6. Crop: condition corn, good except north edge, root depth 4 ft

7. Soil: texture sandy loam, tilth poor other ______

8. Soil Moisture Deficiency ______ in

9. Surface runoff conditions at 3/4 point slight, and at end moderate

10. Speed of outer drive unit 45 ft per 10 min = 4.5 ft/min

11. Time per revolution = $\frac{\text{(outer drive unit radius } 1350 \text{ ft)}}{9.55 \text{ (speed } 4.5 \text{ ft/min)}}$ = 31.4 hr

12. Outer end: water pattern width 165 ft, watering time 39 min

13. Discharge from end drive motor ____ gal per ____ min = ____ gpm

14. System flow ~~(meter)~~ 115,000 gallons per 10 min = 1150 gpm

15. Average weighted catches:

System = $\frac{\text{(sum all weighted catches } 256,255\text{)}}{\text{(sum all used position number } 2044\text{)}} = \frac{125 \text{ ml}}{250}$ = 0.50 in

Low 1/4 = $\frac{\text{(sum low 1/4 weighted catches } 54,908\text{)}}{\text{(sum low 1/4 position numbers } 511\text{)}} = \frac{107 \text{ ml}}{250}$ = 0.43 in

16. Minimum daily (average daily weighted low 1/4) catch:

$\frac{\text{(24 hrs operation/day)} \times \text{(low 1/4 catch 0.43 in)}}{\text{(31.4 hrs/revolution)}}$ = 0.33 in/day

17. Distribution Uniformity (DU) = $\frac{.43}{.50}$ = 86% (good, should be >85%)

Exhibit CO687.71 Center Pivot Sprinkler Irrigation Evaluation Form (continued)

18. Container catch data in units of ml , volume/depth 250 ml/in
Span length 90 ft, container spacing 22.5 ft
Evaporation: initial 150 ml - final 146 ml = loss .02 in

Span No.	Container Position Number	x Catch	Weighted Catch	Span No.	Container Position Number	x Catch	Weighted Catch
1	1	Start numbering at		10	37	118	4366
1	2	pivot end of inner		10	38	127	4826
1	3	span. Do not wait		10	39	115	4485
1	4	for completion of		10	40	147	5880
2	5	irrigation at first		11	41	127	5207
2	6	few containers.		11	42	122	5124
2	7			11	43	118	5074
2	8			11	44	144	6336
3	9	141	1269	12	*45	112	5040
3	10	160	1600	12	46	124	5704
3	11	122	1342	12	47	126	5922
3	12	130	1560	12	48	151	7248
4	13	143	1859	13	49	120	5880
4	14	150	2100	13	50	122	6100
4	15	154	2010	13	51	115	5865
4	16	123	1968	13	52	143	7436
5	17	144	2448	14	53	124	6572
5	18	138	2484	14	*54	114	6156
5	19	135	2565	14	55	115	6325
5	*20	107	4140	14	56	160	8960
6	21	122	2562	15	57	120	6840
6	22	114	2508	15	*58	110	6380
6	23	115	2645	15	*59	109	6431
6	24	138	3312	15	60	117	7020
7	*25	109	2725	16	*61	85	5185
7	*26	113	2938	16	62	194	12028
7	27	114	3078	16	63	148	9324
7	28	126	3528	End	*64	82	5248
8	29	116	3364		65	12	Omit
8	*30	107	3210		66		
8	31	122	3782		67		
8	32	140	4480		68		
9	33	117	3861		69		
9	*34	105	3570		70		
9	*35	111	3885		71		
9	36	125	4500		72		

Sum all: used position numbers 2044 , weighted catches 256,255
Sum low 1/4: position numbers 511 , weighted catches 54,908
Direct average catch 123 ml 0.5 in

Exhibit C0687.72 Sprinkler - Lateral Irrigation Evaluation Form

1. Location__________, Observer__________, Date__________
2. Crop__________, Root zone depth_____, MAD_____%, MAD__________in
3. Soil: texture__________, available moisture_____in/ft, SMD__________in
4. Sprinkler: make__________, model__________ nozzles_____by_____in
5. Sprinkler spacing_____by_____ft, irrigation duration__________hrs
6. Rated sprinkler discharge_____ gpm at_____psi giving__________in/hr
7. Lateral: diameter_____ in, slope_____%, Riser Height__________in
8. Actual sprinkler pressure and discharge rates:

	Sprinkler location number on test lateral						end
Initial pressure (psi)	____	____	____	____	____	____	____
Final pressure (psi)	____	____	____	____	____	____	____
Catch volume (gal)	____	____	____	____	____	____	____
Catch time (min or sec)	____	____	____	____	____	____	____
Discharge (gpm)	____	____	____	____	____	____	____

9. Wind: Temp:

Direction: initial____, during____, final____ ____oF
Speed (mph): initial____, during____, final____

10. Container grid test data in units of ____, volume/depth__________ml/in

Container grid spacing _____ by _____ ft__________
Test: start________, stop________, duration____ hr ____ min = ____ hr

____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____
____	____	____	____	____	____	____	____	____	____	____

11. Evaporation container: initial ____ final ____ loss ____ in
12. Sprinkler pressures: max____ psi; min ____psi; average__________psi
13. Comments:__________

C0687.73

Exhibit C0687.73 Example, Sprinkler - Lateral Irrigation Evaluation Form (Periodic Move)

1. Location Fu 120 Blk 89, Observer JLM, Date 9/30/85
2. Crop Tomatoes, Root zone depth 4.0 MAD 50%, MAD 4.4 in
3. Soil: texture clay loam, available moisture 2.2 in/ft, SMD 4.4 in
4. Sprinkler: make Rain Bird, model 29B nozzels 5/32 by ______ in
5. Sprinkler spacing 30 by 50 ft., Irrigation duration 23.5 hrs
6. Rated sprinkler discharge 4.4 gpm at 40 psi giving 0.28 in/hr
7. Lateral: diameter 2 in, slope 1-1/2%, Riser height 18 in
8. Actual sprinkler pressure and discharge rates:

Sprinkler location number on test lateral

	1	4	5	6	10	15	end
Initial pressure (psi)	45	40	40	40	39	40	
Final pressure (psi)	45		40		39	40	
Catch volume (gal)	1.0	1.0	1.0	1.0		1.0	
Catch time (min or sec)	12.6	12.2	13.2	13.2		13.2	
Discharge (gpm)	4.8	4.6	4.6	4.6		4.6	

9. Wind: Temp.

Direction: initial ____, during ____, final ____ 85 °F

Speed (mph): initial 2+, during 5+ final 5+

10. Container grid test data in units of ml, volume/depth 200 ml/in

Container grid spacing 10 by 10 ft Both sides of set 2

Test: start 2:55 pm, stop 4:30 pm, duration 1 hr 35 min = 1.58 hr

	0	32	68	77	90	73	66	9	0	0
30'	0	35	66	84	100	100	52	3	0	0
	0	32	50	60	104	99	48	12	0	0
	0	31	74	88	104	86	46	11	0	0
	0	27	64	80	96	112	62	9	0	0
		20	49	59	107	87	36	13	0	0
					2					3

2.15 final 2.10 loss 0.05 in

psi; min 39 psi; average 40 psi

short. Depths caught measured in

l velocities are less than normal.

Exhibit C0687.74 Traveling Sprinkler Irrigation Evaluation Form

1. Location________________, Observer____________________Date_________

2. Crop__________________, Root zone depth -_____ft, MAD_____%, MAD______

3. Soil: texture________________, available moisture______________in/ft

4. SMD: near tow path______in, at 1/4-point_____in, at mid-point_______in

5. Sprinkler/Traveler makes and models_______________ / ________________

6. Nozzle: size_____in, type_________, pressure____psi, discharge_____gpm

7. Hose: length____ft, diameter____in, type___________________________

   inlet pressure______psi, outlet pressure______psi

8. Drive: type________, discharge (if piston)__--__gal/__--__min = _-_min

9. Towpath: spacing____ft, length_____ft, slope + ______0______%

10. Evaporation loss: initial - final volume =______ml -______ml =______in

11. Traveler speed check at:
    beginning ______ft/ ______ min = ________ft/min
    at test site ______ft/ ______ min = ________ft/min
    terminal end ______ft/ ______ min = ________ft/min

12. Total: discharge____________gpm, pressure loss_________________psi

13. Average application rate:

$$\frac{96.3 \times (\text{sprinkler discharge \_\_\_\_\_\_ gpm}) \times 360}{(\text{towpath spacing \_\_\_\_\_ ft})^2 \times (\text{wet sector \_\_\_\_\_}^\circ)} = \text{\_\_\_\_\_\_ in}$$

14. Average depth applied:

$$\frac{96.3 \times (\text{sprinkler plus piston discharge \_\_\_\_\_\_ gpm})}{60 \quad (\text{path spacing \_\_\_\_\_ ft}) \times (\text{travel \_\_\_\_\_ ft/min})} = \text{\_\_\_\_\_\_ in}$$

15. Average overlapped catches:

$$\text{System} = \frac{(\text{sum all catch totals \_\_\_\_\_ in})}{(\text{number of totals \_\_\_\_\_})} = \text{\_\_\_\_\_\_ in}$$

$$\text{Low 1/4} = \frac{(\text{sum of low 1/4 catch totals \_\_\_\_\_ in})}{(\text{number of low 1/4 totals \_\_\_\_\_})} = \text{\_\_\_\_\_\_ in}$$

16. Comments: (wind drift, runoff, etc.): ______________________________

____

____

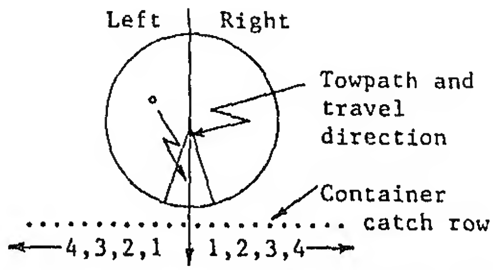
Exhibit C0687.74 Traveling Sprinkler Irrigation Evaluation Form (continued)

17. Container test data in units of ________, Volume/depth ____________ml/in

Wind: speed _________mph

Temp: _______________°F

Note part circle operation and the dry wedge size in degrees.



Left side of path: Start with number 1 opposite the towpath spacing and number down.

Right side of path: Start with number 1 at bottom of column and number up.

Path Spacing (feet)	Container Catch Volume				Right plus Left	
	Left side of path		Right side of path		Side Catch Totals	
	Catch No.	Catch	Catch No.	Catch	ml	Inches
330	1		33			
320	2		32			
310	3		31			
300	4		30			
290	5		29			
280	6		28			
270	7		27			
260	8		26			
250	9		25			
240	10		24			
230	11		23			
220	12		22			
210	13		21			
200	14		20			
190	15		19			
180	16		18			
170	17		17			
160	18		16			
150	19		15			
140	20		14			
130	21		13			
120	22		12			
110	23		11			
100	24		10			
90	25		9			
80	26		8			
70			7			
60			6			
50			5			
40			4			
30			3			
20			2			
10			1			
			Sum of all catch totals			
			Sum of low 1/4 catch totals			

Exhibit C0687.75 Example, Traveling Sprinkler Irrigation Evaluation

1. Location Field 200, Observer JK, Date 8/5/85
2. Crop Corn, Root zone depth 4.0 ft, MAD 35 %, MAD 2.1 inches
3. Soil: texture fine sandy loam, available moisture 1.5 in/ft
4. SMD: near tow path 2.1 in, at 1/4-point 2.2 in, at mid-point 3.7 in
5. Sprinkler/Traveler makes and models Nelson 201 / Heinzman 6645
6. Nozzle: size 1.5 in, type ring, pressure 100 psi, discharge 500 gpm
7. Hose: length 660 ft, diameter 4 in, type lay-flat

   inlet pressure 137 psi, outlet pressure 110 psi
8. Drive: type turbine, discharge (if piston) -- gal/ -- min = - min
9. Towpath: spacing 330 ft, length 1320 ft, slope ± 0 %
10. Evaporation loss: initial - final volume = 500 ml - 470 ml = .15 in
11. Traveler speed check at:

beginning	9.5 ft/	10 min =	0.95 ft/min
at test site	10.0 ft/	10 min =	1.0 ft/min
terminal end	10.2 ft/	10 min =	1.02 ft/min

12. Total: discharge 500 gpm, pressure loss 37 psi
13. Average application rate:

$$\frac{96.3 \times (\text{sprinkler discharge } 500 \text{ gpm}) \times 360}{(\text{towpath spacing } 330 \text{ ft})^2 \times (\text{wet sector } 345\ ^\circ)} = 0.46 \text{ in/hr}$$

14. Average depth applied:

$$\frac{96.3}{60} \times \frac{(\text{sprinkler plus piston discharge } 500 \text{ gpm})}{(\text{path spacing } 330 \text{ ft}) \times (\text{travel } 1.0 \text{ ft/min})} = 2.43 \text{ in}$$

15. Average overlapped catches:

$$\text{System} = \frac{(\text{sum all catch totals } 74.87 \text{ in})}{(\text{number of totals } 33)} = 2.27 \text{ in}$$

$$\text{Low } 1/4 = \frac{(\text{sum of low } 1/4 \text{ catch totals } 12.91 \text{ in})}{(\text{number of low } 1/4 \text{ totals } 8)} = 1.61 \text{ in}$$

16. Comments: (wind drift, runoff, etc.): no evidence of serious wind drift or runoff; crop was stunted midway between paths.

C0687.75

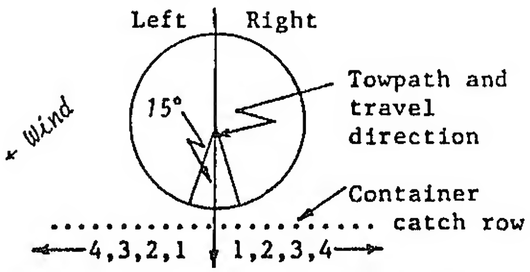
Exhibit C0687.75 Example, Traveling Sprinkler Irrigaiton Evaluation (continued)

17. Container test data in units of ml, Volume/depth 200 ml/in

Wind: speed 5-10 mph

Temp: 70 °F

Note part circle operation and the dry wedge size in degrees.



Path Spacing (feet)	Container Catch Volume				Right plus Left	
	Left side of path		Right side of path		Side Catch Totals	
	Catch No.	Catch	Catch No.	Catch	ml	Inches
330	1	560	33		560	2.80
320	2	540	32		540	2.70
310	3	510	31		510	2.55
300	4	490	30		490	2.45
290	5	505	29		505	2.53
280	6	475	28		475	2.38
270	7	480	27		480	2.40
260	8	460	26		460	2.30
250	9	430	25		430	2.15
240	10	410	24		410	2.05
230	11	370	23		370	1.85
220	12	325	22		325	1.63
210	13	305	21		305	1.53
200	14	345	20		345	1.73
190	15	335	19		335	1.68
180	16	310	18		310	1.55
170	17	305	17		305	1.53
160	18	290	16	35	325	1.62
150	19	250	15	75	325	1.62
140	20	230	14	120	350	1.75
130	21	215	13	215	430	21.5
120	22	165	12	365	530	2.65
110	23	95	11	410	505	2.52
100	24	65	10	515	580	2.90
90	25	25	9	540	565	2.82
80	26	---	8	525	525	2.62
70			7	500	500	2.50
60			6	490	490	2.45
50			5	470	470	2.35
40			4	490	490	2.45
30			3	540	540	2.70
20			2	605	605	3.02
10			1	625	625	3.12
			Sum of all catch totals			74.87
			Sum of low 1/4 catch totals			12.91

Left side of path: Start with number 1 opposite the towpath spacing and number down.

Right side of path: Start with number 1 at bottom of column and number up.

Exhibit C0687.76 - Furrow Intake Data Sheet

Owner ____________________ CD ______________ County ____________

Legal Description __________________ Date _________ By: ___________

Soil Series-Mapped _________________ Actual _________ Slope __________

Furrow Condition (Circle): Loose Slick (packed) Firm

Restrictive Layers: Surface Crusting - Yes___ No___
Tillage Plan - Yes___ No___ Depth _____
Other__________ Depth _____

Normal Set Time _____Hrs. Frequency _____ Days Ave. Stream _____GPM

Soil Moisture (Before) Soil Moisture _____Hrs (After)

_____ 6" _____ 12" _____ 36" _____6" _____12" _____36"

Present Crop __________ Crop _____Yr __________ Crop _____Yr __________

Furrow Erosion:

Upper Third (Circle)	Deposition	None	Slight	Moderate	Severe
Middle Third (Circle)	Deposition	None	Slight	Moderate	Severe
Lower Third (Circle)	Deposition	None	Slight	Moderate	Severe

Furrow Spacing (in.) _____ Irrigation Pattern Adjacent Every ____ Furrow

Average Furrow Length _____ Stream Size to Field __________

Field Width __________ Normal Seasonal Number of Irrigations _____

Irrigation Number (Circle): 1st 2nd 3rd 4th 5th 6th 7th 8th ___

Comments: (Such as crop condition, excessive wet areas, field grade uniformity, etc.)

C0687.76

Exhibit C0687.76 Furrow Intake Data Sheet

Farm ____________________ SCD __________________________ Sheet _____ of _____

Location ____ By _______________

Furrow No. _________ Station ____________ Inflow _________ Date _____________

Measuring Device ______________________ Outflow _________

(1) Clock Time* (hrs)	(2) Elapsed Time (min)	(3) Incremental Time (min)	(4) Gage Height (in.)	(5) Flow Rate (gpm)	(6) Average Flow Rate (gpm)	(7) Volume of Flow (gal)	(8) Cumulative Volume (gal)	(9) Advance Time	(10)	(11)
								Clock Time* (hrs)	Elapsed Time (min)	Station (ft.)

facilitates computations.

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Part 688 - Conservation Irrigation Systems Planning

Part 688 - Conservation Irrigation Systems Planning

SUBPART A - GENERAL

C0688.1 Introduction.

(a) The material in this section of the Irrigation Guide i intended to help soil conservationists and technicians assist landowners in planning their irrigation system(s).

(b) Basic to the planning process is the ability to determine which irrigation systems will fit site conditions. Part C0684, Irrigation Method Selection and Part C0685, Irrigation Method and Design Criteria, will assist in this selection process.

(c) This part gives a logical approach to thinking through planning an irrigation system. It should be recognized that there will be many variations required on individual farms. Th planner should feel free to adopt any variations needed.

(d) Worksheets needed for planning irrigation systems may b developed to fit the individual planners circumstances.

Part 688 - Conservation Irrigation Systems Planning

SUBPART B - CONSERVATION IRRIGATION PLAN REQUIREMENTS

C0688.10 Conservation irrigation.

(a) Conservation irrigation is defined as the use of irrigated soils and irrigation water in a way that ensures high production without wasting either water or soil resources. It is using cropping, irrigation, and cultural practices capable of maintaining the land in permanent agriculture. To an irrigator, it means saving water, controlling erosion, improving crop yield, lowering production costs or increasing net return, and maintaining productivity of the irrigated land.

(b) A conservation irrigation system is the complete arrangement of the delivery and application facilities needed to distribute irrigation water efficiently to all land served by the system.

C0688.11 Plan requirements.

An irrigation plan can be divided into two parts:

(a) An irrigation system plan which provides for the delivery and application of the water.

(b) An irrigation water management plan which provides for the proper use of water delivered. The plan should provide data that can be used by the irrigator based on his management ability and degree of expertise in irrigation.

SUBPART C - IRRIGATION SYSTEM PLAN CONTENT

C0688.20 Irrigation system plan.

(a) Irrigation water must be applied uniformly and efficiently. For furrow irrigation, land slopes should be as uniform as possible. The length of run should be appropriate for good application. In sprinkler irrigation, the sprinkler heads should be sized and spaced properly to get good uniformity of application whether on center pivots, side rolls, traveling big guns, permanent solid set, or movable solid set, etc. Irrigation efficiency should be high.

(b) Tailwater should be reused when possible or disposed of safely.

(c) Storm water should be removed from the site without excessive erosion or other problems.

(d) The water supply should be measured on an on-going basis so determinations can be made as to irrigation efficiency and proper water use. Rate and duration of flow (gpm or cfs) should be measured so that the total volume of applied water can be determined (ac-ft or ac-in.).

(e) Access should be provided to all areas for easy operation of the irrigation system, for normal farming operations and for removal of produce. This may involve culverts in ditches, access roads, etc..

(f) Cost guidelines should be provided for installation and operation of the irrigation system, including energy costs.

C0688.21 Planning steps.

(a) Preliminary considerations.

(1) Consider the whole farm or ranch unit even if the farmer is interested in only one field. This will ensure that pipelines, ditches, etc., will be of an adequate size and elevation to service all the land units. Implementation of the plan may begin with one field, one ditch, or one pipeline and may continue for several years. Revisions may be necessary before the whole system is completely installed.

(2) The irrigator may have strong feelings about certain systems. At the same time he deserves information on the best available systems that will meet his needs. Pros and cons, including labor requirements and economic considerations, of the "best fit" systems need to be provided. The farmer can then make a logical choice from the alternatives presented.

(3) What is the availability, quality, and adequacy of the farm water supply? How is the irrigation water delivered and on what schedule? An adequate and dependable source of good quality water must be available or there must be the possibility of developing one.

C0688.22 Basic data needs.

(a) Soils.

(1) Determine the intake family if considering surface irrigation methods - furrow intake family for furrows; cylinder intake family for borders; maximum sprinkler rate for sprinkler irrigation if sprinklers are being considered.

(2) Determine water holding capacity to the depth of the root zone of the crops being considered. (See Section C0681.20).

(3) Determine if salt problems exist and the need for leaching and/or drainage to control water table.

(b) Crops.

(1) Compare water availability to crop use and area irrigated. Recommend crop changes where shortage exist. (See Part 683, Subpart F).

(2) Develop monthly water budgets.

(c) Topography. Show high points in each field and direction of irrigation and drainage. A survey with an engineering instrument may be needed.

(d) Water supply quantity, quality, location and elevation.

(e) Existing physical features. What is the access to all parts of the irrigated area? Location of public roads, utility lines, building, other?

surface features. Location of seeps and how to cut
eral drainage installed or needed?

ng irrigation system. Location, sizes, condition.
ate? Will it fit the proposed improvements?

t farm operations. What equipment is used? What
ure operations? Eight (8) row or four (4) row
affect set width.

C0688.23 Planning the system.

(a) Decide on the type(s) of system(s) that will be used. Sprinkler, basin, furrow, etc..

(b) Develop and plan field arrangements, considering:

- method of irrigation;
- workability, shape and access to field;
- direction of irrigation; and
- benefits to be derived from the change.

C0688.24 The irrigation system plan.

(a) Furrow or corrugation irrigation. Elements to consider:

- gated pipe; cablegation, surge irrigation;
- ditches with siphon tubes;
- turnout structures;
- irrigation slope;
- length of run;
- tailwater recovery or disposal;
- furrow spacing; and
- cross-slope, etc..

(b) Sprinkler irrigation. Elements to consider:

- type of system - center pivot, side roll, solid set, traveling big gun;
- maximum application rate;
- lateral and mainline pressure - gravity or pumped;
- sprinkler head discharge; and
- lateral and head spacings.

(c) Border irrigation. Elements to consider:

- length of run;
- tailwater disposal;
- border strip widths;
- grade of border; and
- border ridge height.

C0688.25 Water distribution system plan.

(a) Determine structures needed to get the water from the source to the farm at proper location, elevation, pressure and quantity; and into the distribution systems, i.e., types of turnout, well location(s), irrigation company requirements.

(b) Determine number, location, and type of water measurement structures needed, such as flumes, propeller meter, etc.

(c) Determine field turnout facilities. Structures, gated pipe, pipelines, and valves.

(d) Estimate the cost of the alternatives evaluated.

C0688.26 Tailwater reuse system.

Items to be considered are:

- tailwater pit size;
- pipeline for pumpback system or gravity flow system to lower field;
- pumping plant needs; and
- location of tailwater sump and other structures.

C0688.27 Farm road system.

There should be access to all parts of the irrigation distribution system for ease of maintenance and operation and field access for planting, tillage and harvesting operations.

C0688.28 Subsurface drainage system.

Items to be considered are:

- location of seeps;
- high water table;
- depth and location of drains; and
- necessary outlets.

C0688.29 Maintenance program.

(a) Develop a program to maintain conservation practices.

(1) For concrete lined ditches. Remove vegetation when necessary, clean out debris and soil from ditch, fix cracks.

(2) Pipelines. Repair leaks, see that valves are operating properly.

(3) Structures and measuring devices. Maintain in working order and good repair.

(4) Sprinklers. Check for nozzle plugging and wear.

(5) Pumps and motors. Perform periodic maintenance. Avoid shutdowns.

SUBPART D - IRRIGATION OPERATION PLAN

C0688.30 Water management.

Operating criteria for application of water under varying conditions needs to be specified and the following items considered:

- how fast does the soil absorb water;
- how much moisture is to be replaced each irrigation;
- the depth of a normal application for crops to be grown;
- provisions for variation in application requirements;
- number of borders, furrows, sprinkler laterals, etc. per set;
- number of sets and stream size per set; and
- guidelines for evaluation by the farmer.

C0688.31 Irrigation frequency.

(a) The irrigation frequency can be estimated if the consumptive use is known. Divide the inches of readily available moisture held in the rooting depth of the soil by the daily consumptive use rate in inches to estimate the number of days between irrigations.

(b) Before irrigating, check the soil moisture in the root zone at several locations. Estimate the amount of water needed to bring the soil to field capacity. If it appears that the soil is within 20 percent of field capacity, the irrigation may be delayed. About two or three days after an irrigation, check the soil moisture again. The moisture should be close to field capacity throughout the rooting depth. There should be no dry spots in the field or dry layers in the soil profile.

C0688.32 Time of application.

(a) For any irrigation method used, it can be assumed that a uniform soil will absorb about the same amount of water in one location in a field as in another part, if the water is in contact with the soil for the same length of time in each place. In other words, if intake, "opportunity-time" is the same at all points in the field then a uniform application of water would be expected over the entire field. Most irrigation methods do not permit water to be applied for exactly the same length of time at all locations in the field, but can be made to approach this ideal goal.

(b) Determine the time of application for an irrigation. This will affect the size of the stream used, the depth of application planned and the area in acres to be irrigated from each set. Dividing the area by the stream size in acre-inches per hour and multiplying by the depth of application will give the time of application.

CO688.32(c)

(c) During an irrigation, watch to see whether the intake opportunity-time is about the same throughout the field. When irrigating with borders, does the water stand about as long at the lower end and middle of the field as it does at the upper end? For furrows, does the water reach the lower end at about one-fourth of the total time that it is on the upper end? Are basins and level borders filled quickly?

CO688.33 Flow rates.

(a) The size of stream should be large enough in borders so that the water spreads sufficiently to get complete coverage. It should not be so large that erosion will occur.

(b) The stream size in furrows should be large enough so that the waterfront reaches the distal end of the furrow between one-fourth and one-half of the total application time.

(c) Observe the amount of irrigation water running off the surface of the field. A large amount of surface runoff from a border indicates the stream is too large or that water has been run into the border strip for too long a time. When the water in a well-designed graded border approaches the lower end of the strip, the stream may be reduced at the upper end. In this way an even distribution will be obtained with little or no runoff. The stream size must be properly adjusted to the soil intake rate and to the border length if the border is to be evenly irrigated without excessive runoff. If furrow runoff is excessive, the furrow stream should be reduced to about one-third to two-thirds of the initial flow after the water reaches the lower end.

(d) When the intake opportunity-time for a soil is excessively long and runoff occurs, the use of a tailwater pit and pump back or other re-use system should be considered.

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Part 689 - Economic Evaluations

Part 689 - Economic Evaluations

SUBPART A - GENERAL

CO689.1 Use of economic evaluations.

(a) Proper use of economic tools and procedures will provide cost and return information for alternative courses of action. With good economic data, an individual can make an informed decision as to the system that best fits his operations.

(b) This section will be helpful in determining what an irrigation system will cost and how to estimate the change in income from the use of the system. The average annual cost of irrigating is compared to the value of the annual increase in production. The change in income may be a deciding factor as to the type of system that should be purchased.

(c) The procedure for evaluating alternative irrigation systems is very flexible. It can be used to evaluate a single portion of a system, any combination, or an entire operating system or unit. The basic principal is to use identical procedures for evaluating two or more alternatives for the same land area. The amount of the difference between the systems evaluated is the basis for making a decision.

SUBPART B - IRRIGATION COST AND RETURNS

C0689.10 Cost and return form.

(a) The Irrigation Cost and Return Form is divided into the following sections:

I. Determining the annual ownership cost.
II. Determining the annual operation and maintenance cost.
III. Determining the return on investment.

(1) Each section is further divided into steps that coincide with the form. (See Subpart C - C0689.20 Exhibit A for blank form for your use.)

(b) Section I. The Annual Ownership Cost per Acre

The annual ownership cost per acre is determined by obtaining:

Estimated cost of capital.
Estimated cost of owner's equity.
Estimated cost of taxes and insurance.
(See completed form in Subpart B C0689.11 Example that coincides with narrative).

(1) In Section I, it is necessary to charge interest on all capital, whether it is borrowed or owner supplied. If borrowed, the lender demands "rent" or interest on his capital. The interest rate generally used on all capital is the present loan rate. The capital supplied by the owner could have been loaned at interest or used by the owner for other capital investments. The use of owner supplied capital represents the opportunity foregone in investing in other income-producing enterprises; therefore, it too needs to be charged interest.

(2) The life expectancy of major items of the system is generally used as the length of the amortization period. In some irrigation systems, there are major items that have different life expectancies. For those cases, each needs to be amortized separately. Amortization is a method of converting costs into equal payments over a specified time period. Usually the time between payments is one year since benefits are on an annual basis. To analyze whether the alternative is profitable, costs and benefits must be for the same time frame. However, though a system may last 15 to 20 years, many lending agencies require that they be paid for in ten years or less. The length of the loan then determines the period of amortization.

C0689.10(b)(2)

For example, to borrow $25,000 to buy a system, the payments may range from $2500 to $6000 per year. The increased income from the irrigation system may be only $3500 per year. In this case, be prepared to supplement the loan payments with money other than that expected from irrigating or use the time/period of the loan when analyzing its profitability.

(3) Example:

(i) 25,000 borrowed at 12% for 10 years will cost $4424 per year (25,000 x .17698) (Table C0689.40)

(ii) However, $25,000 borrowed at 12% for 25 years will cost $3188 per year (25,000 x .12750)

(iii) If the increased return from irrigation is $3500 per year, loss of $924 per year will occur in (i) and a profit of $312 per year in (ii).

(4) Complete Section I to obtain the annual ownership cost per acre. The following step by step method will be helpful in filling out the Irrigation Cost and Return Form. Each step corresponds with the step in Section I of the form.

(i) Step 1. Estimate the cost of capital for the Irrigation System planned.

(a) Find the appropriate amortization factors in Table C0689.40 Subpart D. Amortization factors depend on the length of life of the particular item (or the loan period) and the present interest rate. Annual cost is computed by multiplying the amount of capital by the appropriate amortization factor. The interest rate generally used on all capital is the present loan rate. Twelve (12) percent is used in this example.

(b) The annual cost for the $45,500 in capital is $6870, ($4840 + 1140 + 890). This does not include $455 in taxes and insurance. The total is $7325.

(ii) Step 2. Estimate the cost of owner's equity. The owner's equity is considered to be the trade-in value of the old system. In this example $0 is used. The interest rate used for developing the cost of the owner's equity is normally the rate paid on savings accounts. Current rates are 6-9 percent. (Total: $0.)

(iii) Step 3. Estimate the annual increase in cost of taxes and insurance. The example uses an estimate of one percent of total initial cost. (Total: $45,500 X .01 = $455.)

(iv) Step 4. <u>Estimate total annual ownership cost per acre</u>. Total annual ownership cost is $7325 (Step 1 + Step 2 + Step 3) . The estimated annual ownership cost per acre is found by dividing the total annual cost by the estimated acreage developed. (126 acres in this example). (Total: $7325 / 126 = $58.10)

(c) Section II. The Annual Operation and Maintenance Cost

(1) Annual operation and maintenance (O&M) cost is determined for the alternative being planned. The costs include: fuel, repair and maintenance (power unit), repair and maintenance of equipment, and reservoir and field maintenance. Each step in this section corresponds with the steps in Section II of the form.

(2) Annual O&M cost for a system is developed by following Steps 1 through 5 of the Cost and Return Form. Historical expenditures for operating and maintaining similar systems expressed annually may be used if known.

(i) Step 1. Find the total annual energy cost. This includes the standby charges for electricity which can be obtained from local power suppliers. Record the Energy Cost in Step 1.

(a) $.07 per KWH for electricity was used in the example.

(b) Total: The total fuel cost was $5200 for fuel + 800 for standby charges or a total of $6000.

(ii) Step 2. Estimate the annual cost of maintenance of the power unit and record it.

(a) Table C0689.41 gives the cost of power unit repair and maintenance per water horsepower per hour. Record the applicable values and follow the mathematical instructions. It is negligible in this example.

Total: $0.

(iii) Step 3. Estimate the annual cost of repair and maintenance of the irrigation equipment.

(a) The cost of repair and maintenance of the irrigation equipment was estimated at 2.5 percent of the total initial cost. The estimated repair and maintenance generally averages 1-5% of the initial cost.

Total: $45,500 (initial cost) X .025 = $1140.

(iv) Step 4. Estimate the total annual cost of reservoir and field maintenance.

(a) For this example, no cost was figured for reservoir and field maintenance.

(b) If reservoir or field maintenance is required, estimate and record in the Cost and Return Form. The Estimated cost per year averages 1-3% of the initial cost.

(v) Step 5. Estimate the total annual operation and maintenance cost per acre.

(a) Add the "Total" column (summation of Steps 1 through 4) and divided by acreage being planned.

Total: Annual operation and maintenance cost per acre is $56.67 ($7140/126).

(d) Section III. The Return on Investment

(1) Compare the net return between irrigation systems or portions of irrigation systems. Comparisons may include:

(i) Value per acre from expected increased production.

(ii) Change in production costs per acre.

(iii) Change in labor costs per acre.

(iv) Difference in annual ownership costs per acre.

(v) Difference in O&M costs per acre.

(vi) Change in income due to taking acreage out of production or put into production.

(vii) Cost of fuel, repair, and maintenance of present irrigation system. Not all of these will change for each alternative, therefore, only change the applicable ones. Each step in this section corresponds with Section III of the Cost and Return Form. Complete Section III to compare which alternative is the most cost effective.

(2) Step 1. Estimate the value of the expected increase in production per acre. Follow the mathematical instructions in Cost and Return Form. In some instances there may be no changes in yield.

Total: $286.00 per acre increase expected from higher corn yields (110 bu. increase).

(3) Step 2. Estimate the annual per acre change in production costs for the irrigation system being analyzed.

(i) Estimate the change in production costs such as seed, fertilizer, pesticides, water, labor, harvesting, handling or storage that would occur when comparing an irrigation system to one without irrigation or with the present irrigation system. Table C0689.43 is useful when the only production cost changes are in harvesting costs due to yield increases.

(ii) The budgets in Subpart C, Exhibits B & C, illustrate the estimated increase in production costs between dryland and irrigated corn of $154.75. These production cost increases per acre are the differences in the sum of the total variable and ownership costs for irrigated cropland ($247.50) and dryland ($92.75). In some instances there will be little or no change in the production costs per acre. The estimated production cost increase should be entered in Section III, Step 2, of the Cost and Return Form.

Total: $154.75 per acre increase in production costs.

(iii) Other budgets may be found in Colorado Economic Handbook.

(4) Step 3. Estimate the annual cost per acre change in irrigation labor use. An increase in use of irrigation labor is a cost while a decrease is a benefit to the alternative. This example estimates that there will be a .60 hour increase in labor. This estimate was developed using Table C0689.44 which illustrates the average labor use per acre per irrigation. Compute the average change in irrigation labor per acre (in this case a .60 hour increase per acre):

(i) _____ hours per acre irrigation X _____ irrigations X $_____ per hour cost of labor.

Total: Estimated increase in irrigation labor cost is $2.40 per acre (.6 hours X 4.00).

(ii) The change in per acre labor usage cost of compared alternatives is the cost or benefit to that alternative.

(iii) An additional example would be changing from furrow to center pivot. The decrease in labor used is .65 hrs/irrigation (.75 - .10). Multiply .65 times the number of irrigations times the price of labor to obtain the benefit in decreased labor use.

(5) Step 4. Insert the annual ownership cost per acre as computed in Section I of the Cost and Return Form.

C0689.10(d)(5)

Total: Estimated annual ownership cost is $58.10 per acre.

(6) Step 5. Insert the annual operation and maintenance cost per acre as computed in Section II of the Cost and Return Form.

Total: Estimated operation and maintenance cost is $56.67.

(7) Step 6. Estimate the value of lost or gained production from land that is taken out of or put into production.

(i) In this example, no loss is involved since a well supplies the water and it does not take up much land. If a lake, pond or reservoir is constructed consider the loss of production--if the land is used for this purpose. If the irrigation system is of the type that causes other land to be taken out of production, this loss of production should also be considered. The value per year of land taken out of production is based on past production for the acreage lost. Also if additional land is put into production, use the same procedure except that it is a benefit.

(ii) The total value of production is then divided by the total acreage being planned to develop a cost per acre from land taken out of production. The formula to use is as follows: dollars per acre net return on your past production times number of acres taken out of production divided by number of acres being planned by the alternative.

Total: Estimate $0 per acre for the example.

(8) Step 7. Estimate the total fuel cost and repair and maintenance of the former power unit, irrigation equipment, reservoir, and field maintenance for the acreage being planned. Annual historical expenditures should be used. In this example, no cost was used.

(i) The cost for the above are a benefit to the alternative being analyzed and should be on a per-acre basis.

Total: Estimated $0 per acre for this example.

(9) Step 8. Estimated change of income per acre. The estimated change of income per acre is the sum of Steps 1 through 7 of Section III of the Cost and Return Form.

(i) If the benefits are greater than the costs, the estimated change in income from the alternative will be positive. If two alternatives have benefits that are equal, then the alternative that is least costly is the more viable alternative.

Total: Estimated change in income per acre for the example is $14.58.

(e) Finally, tax advantages from investment credit and government cost sharing, though not included here, can reduce the cost per acre to the farmer and increase his income.

(1) Additional alternatives may be compared in the same manner. Exhibits D, E and F are additional examples using the Cost and Return Form. Exhibits G-L also compare portions of irrigation systems as to which alternative is less costly or has a higher return.

C0689.11 Example Cost and Return

IRRIGATION COST AND RETURN FORM

126 acres planned — Center-pivot (Type Irrigation systems)
6 # of irrigations

Section I — ANNUAL OWNERSHIP COST

Item	Annual Costs
Step 1. 1/ Estimated cost of:	
a). Capital for Irrigation System \$ 30,000 X .16144 (Amortization factor) Center pivot - 12 year life	\$4,840
b). Well & electric pump \$ 8,500 X .13388 20 year life	\$1,140
c). Plastic pipelines-25 yr. life \$ 7,000 X .12750	\$ 890
Step 2. 2/ Cost of Owners Equity: \$ ___ X ___ (interest rate)	\$ 0
Step 3. Taxes and Insurance:	\$ 455
Step 4. Total Annual Ownership Costs:	\$7,325
Average Annual Ownership cost/acre:	\$ 58.10

Section II — ANNUAL OPERATION AND MAINTENANCE COST

	Total
Step 1. Fuel: Energy usage 74,300 (KW) X \$ .07 price + \$800 standby charge.	\$6,000 3/
Step 2. Repair & Maintenance Horse Power 4/ (power unit) Required ___ X Operated ___ X \$___ per Whp/hr.	\$ 0
Step 3. Repair & Maintenance: 2.5% of total initial cost. (irrigation equipment; Sec. 1, Step 1 a+b+c)	\$1,140
Step 4. Reservoir & Field Maintenance: 0 % of total initial cost.	\$ 0
Step 5. Total Annual Operation & Maintenance Cost	\$7,140
Annual Operation & Maintenance cost/acre	\$ 56.67

Section III — RETURN OF INVESTMENT

	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: 110 yield per acre increase X \$2.60 per unit (bushels, pounds, tons, etc.)	\$ 286.00
Step 2. Anticipated additional Production costs per acre:	
Step 3. Change in irrigation labor	

C0689.11 Example Cost and Return (cont.)

IRRIGATION COST AND RETURN FORM

126 acres planned
6 # of irrigations

Center-pivot (Type Irrigation system)

Section III	RETURN OF INVESTMENT	
Step 4.	Insert annual ownership cost per acre from Section I	$- 58.10
Step 5.	Insert annual operation and maintenance cost per acre from Section II:	$- 56.67
Step 6.	Loss of income due to acreage out of production	$ 0
	Step 7. Cost of fuel, repair, and maintenance of the present irrigation system on a per-acre basis.	$ 0
Step 8.	Estimated change in income per acre for the analyzed alternative:	$ 14.58

1/ Estimated average life of system found on Table C0689.42.
12 % interest rate used. Use Table C0689.40.

2/ ____ % interest rate for trade-in was used.

3/ See Exhibit M Pump Irrigation Efficiencies and costs to estimate energy usage. Used 15" of water 65%, efficiency and 300 ft. of head.

4/ Estimated cost per Whp per hour found in Table C0689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table C0689.43.

6/ Estimated average irrigation labor use per acre per irrigation may be found in Table C0689.44.

SUBPART C - EXHIBITS

C0689.20 Exhibit A

IRRIGATION COST AND RETURN FORM

___ acres planned
___ # of irrigations

__________ (Type of Irrigation System Change)

Section I	ANNUAL OWNERSHIP COST	
Item		Annual Costs
Step 1. 1/Estimated Cost of:		
a). Capital for Irrigation System $___ X ___(Amortization factor)		$_______
b). ____________________		$_______
c). ____________________		$_______
Step 2. 2/Cost of Owners Equity: $_____ X_____(interest rate)		$_______
Step 3. Taxes and Insurance:		$_______
Step 4. Total Annual Ownership Costs:		$_______
Average Annual Ownership cost/acre:		$_______

Section II	ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage___(gal.,KW) X $____price + $_____ standby charge.		$_____ 3/
Step 2. Repair & Maintenance Horse Power 4/ (power unit) Required____ X Operated____ X $____ per Whp/hr.		$_______
Step 3. Repair & Maintenance: _____% of total initial cost. (irrigation equipment; Sec. 1, Step 1 a+b+c)		$_______
Step 4. Reservoir & Field Maintenance: ____% of total initial cost.		$_______
Step 5. Total Annual Operation & Maintenance Cost		$_______
Annual Operation & Maintenance cost/acre		$_______

Section III	RETURN ON INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: ______ yield per acre increase X $____ per unit (bushels, pounds, tons, etc.)		$_______
Step 2. Anticipated additional Production costs per acre:	Additional Seed, Water, fertilizer, Chemicals and Harvesting cost (estimate)5/	$_______
Step 3. Change in irrigation labor of ____ hours per acre 6/ X ____ per hour		$_______

C0689.20

C0689.20 Exhibit A (cont.)

IRRIGATION COST AND RETURN FORM

___ acres planned	___________ (Type of
___ # of irrigations	Irrigation System Change)

Section III	RETURN ON INVESTMENT	Total/Acre
Step 4.	Insert annual ownership cost per acre from Section I	$_____
Step 5.	Insert annual operation and maintenance cost per acre from Section II:	$_____
Step 6.	Loss of income due to acreage out of production	$_____
Step 7.	Cost of fuel, repair, and maintenance of the present irrigation system on a per-acre basis.	$_____
Step 8.	Estimated change in income per acre for the analyzed alternative:	$_____

1/ Estimated average life of system found on Table C0689.42.
___% interest rate used. Use Table C0689.40.

2/ ___% interest rate for trade-in was used.

3/ See Exhibit M, Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table C0689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table C0689.43.

6/ Estimated average irrigation labor use per acre per irrigation may be found in Table C0689.44.

C0689.21 Exhibit B

AVERAGE GROSS RETURNS AND PRODUCTION COSTS

CENTER PIVOT IRRIGATED CORN

GROSS RETURNS: 150 bu/Ac. X $2.60/bu. = $390.00

PRODUCTION COSTS 1/:	ESTIMATE
Stalk Chopper 1 X @ $4.50	$ 4.50
Plow 1 X @ $12.00	12.00
Disc, tandem 2 X @ $5.50	11.00
Plant	6.00
Seed Cost .25 bu. @ $70.00	17.50
Fertilizer, applied N + P + K	50.00
Pesticides, Herbicides applied	35.00
Cultivating 2 X @ $5.00	10.00
Harvest	22.00
Miscellaneous costs (taxes, Insurance, pickup, tools)	12.00
Other Costs:	
Total Costs/Acre	$180.00
Costs varying with yields:	
Hauling, drying, cribbing, storage, and spoilage $.45/bu. 3/ X 150/bu. =	$ 67.50
Total Production Costs	$247.50

1/ Figures include tractor and labor cost. Production costs include variable and ownership costs. Does not include irrigation costs.

C0689.22 Exhibit C

AVERAGE GROSS RETURNS AND PRODUCTION COSTS

DRYLAND CORN

GROSS RETURNS: 40 bu/Ac. X $2.60/bu. = $104.00

PRODUCTION COSTS 1/:	ESTIMATE
Stalk Chopper 1 X @ $3.50	$ 3.50
Plow 1 X @ $10.00	10.00
Disc, tandem 1 X @ $5.00	5.00
Plant	6.00
Seed Cost 9 lbs @ $70.00/bu. (@ 56 lbs/bu)	11.25
Fertilizer, applied N	10.00
Cultivating 2 X @ $5.00	10.00
Harvest	15.00
Miscellaneous costs (taxes, Insurance, pickup, tools)	4.00
Other Costs:	
Total Costs/Acre	$ 74.75
Costs varying with yields:	
Hauling, drying, cribbing, storage, and spoilage $.45/bu. 3/ X 40/bu. =	$ 18.00
Total Production Costs	$ 92.75

1/ Figures include tractor and labor cost. Production costs include variable and ownership costs.
Irrigation production costs ($247.50) - Dry cropland production cost ($92.75)= $154.75) additional production costs/acre on coverting to irrigation.

C0689.23 Exhibit D (example 1)

IRRIGATION COST AND RETURN FORM

10 acres planned
___# of irrigations

Drip
Irrigation (Type of
Irrigation System Change)

Section I	ANNUAL OWNERSHIP COST	
Item		Annual Costs
Step 1.[1/] Estimated cost of:		
a). Capital for Irrigation System $ 8,000 X .12750 (Amortization factor) Regulating Reservoir, 1/2" tubing risers, plastic pipe (25-yr life)		$ 1020.00
b). Pump emitters regulators, $ 5,500 X .14682 fittings, water meter (15-yr life)		$ 735.00
c). ________		$ ____
Step 2.[2/] Cost of Owners Equity: $___ X ___(interest rate)		$ ____
Step 3. Taxes and Insurance:		$ ____
Step 4. Total Annual Ownership Costs:		$ 1755.00
Average Annual Ownership cost/acre:		$ 175.50

Section II	ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage _____ (KW) X $_____ price + $_____ standby charge.		$ ____ 3/
Step 2. Repair & Maintenance Horse Power [4/] (power unit) Required ___ X Operated ___X $_____per Whp/hr.		$ ____
Step 3. Repair & Maintenance: 1.5% of total inital cost. (irrigation equipment Sec. 1, Step a+b+c)		$ 195.00
Step 4. Reservoir & Field Maintenance: ___% of total initial cost.		$ ____
Step 5. Total Annual Operation & Maintenance Cost		$ 195.00
Annual Operation & Maintenance cost/acre		$ 19.50

Section III	RETURN OF INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: 120 yield per acre increase X $ 4.50 per unit (bushels, pounds, tons, etc.)		$ 540.00
Step 2. Anticipated additional Production costs per acre:	Additional Seed, Water fertilizer, Chemicals and Harvesting cost (estimate)[5/]	$- 300.00
Step 3. Change in irrigation labor of 3.90 hours per acre[6/] X $4.00 per hour		$+ 15.60

C0689.23

C0689.23 Exhibit D (cont.)

IRRIGATION COST AND RETURN FORM

10 acres planned	Drip
___ # of irrigations	Irrigation (Type of Irrigation System Change)

Section III	RETURN OF INVESTMENT	
Step 4.	Insert annual ownership cost per acre from Section I	$-175.50
Step 5.	Insert annual operatin and maintenance cost per acre from Section II:	$- 19.50
Step 6.	Loss of income due to acreage out of production	$ 0
Step 7.	Cost of fuel, repair, and maintenance of of the present system on a per-acre basis.	$+ 12.00
Step 8.	Estimated change in income per acre for the analyzed alternative:	$ 72.60

1/ Estimated average life of system found on Table C0689.42.
12 % interest used. Use Table C0689.40.

2/ ___ % interest rate for trade-in was used.

3/ See Exhibit M Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table C0689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table C0689.43. $2.50/bu. x 120 bu/acre increase = $300.00/acre.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table C0689.44 comparing the present irrigation system (furrow) to drip irrigation (.75 - .10) = .65 hrs/acre/irrigation savings).

C0689.24 Exhibit E (example 2)

IRRIGATION COST AND RETURN FORM

_10_ acres planned
_6_ # of irrigations

Automated
Furrow (Type of
Irrigation System Change)

Section I ANNUAL OWNERSHIP COST	
Item	Annual Costs
Step 1.[1/] Estimated cost of:	
a). Capital for Irrigation System $ 4,500 X .12750 (Amortization factor) Ditch lining, leveling, pipe (25-yr life)	$ 573.75
b). Automation & measuring devices $4,000 X .14682	$ 587.25
c). ____________	$ ____
Step 2.[2/] Cost of Owners Equity: $ ___ X ___ (interest rate)	$ ____
Step 3. Taxes and Insurance:	$ ____
Step 4. Total Annual Ownership Costs:	$ 1161.00
Average Annual Ownership cost/acre:	$ 116.10

Section II ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage ____ (gal.,KW) X $ ____ price + $ ____ standby charge.	$ 3/
Step 2. Repair & Maintenance Horse Power [4/] (power unit) Required ___ X Operated ___ X $ ____ per Whp/hr.	$ ____
Step 3. Repair & Maintenance: ___ % of total initial cost. (irrigation equipment Sec. 1, Step a+b+c)	$ ____
Step 4. Reservoir & Field Maintenance: _1_ % of total initial cost.	$ 85.00
Step 5. Total Annual Operation & Maintenance Cost	$ 85.00
Annual Operation & Maintenance cost/acre	$ 8.50

Section III RETURN OF INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: _80_ yield per acre increase X $ 4.50 per unit (bushels, pounds, tons, etc.)	$ 360.00
Step 2. Anticipated additional Production costs per acre: Additional Seed Water fertilizer, Chemicals and Harvesting [5/] cost (estimate)	$- 200.00
Step 3. Change in irrigation labor of _3.90_ hours per acre[6/] X $4.00 per hour	$ 15.60

C0689.24

C0689.24 Exhibit E (cont.)

IRRIGATION COST AND RETURN FORM

126 acres planned	Automated
6 # of irrigations	Furrow (Type of Irrigation System Change)

Section III RETURN OF INVESTMENT	Total/Acre
Step 4. Insert annual ownership cost per acre from Section I	$- 116.10
Step 5. Insert annual operation and maintenance cost per acre from Section II:	$ --
Step 6. Loss of income due to acreage out of production	$- 8.50
Step 7. Cost of fuel, repair, and maintenance of of the present system on a per-acre basis.	$+ 12.00
Step 8. Estimated change in income per acre for the analyzed alternative:	$+ 63.00

1/ Estimated average life of system found on Table C0689.42.
12 % interest used. Use Table C0689.40.

2/ ___ % interest rate for trade-in was used.

3/ See Exhibit M, Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table C0689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table C0689.43.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table C0689.44. Comparing furrow to automated furrow (.75 - .1 = .65 hrs/acre/irrigation savings).

C0689.25 Exhibit F (example 3)

IRRIGATION COST AND RETURN FORM

40 acres planned
4 # of irrigations

Corrugations to Sideroll (Type of Irrigation System Change)

Section I	ANNUAL OWNERSHIP COST
Item	Annual Costs
Step 1.[1/] Estimated cost of:	
a). Capital for Irrigation System $12,000 X .13386 (Amortization factor) Sideroll, pipe and other appurtenances.	$ 1600.00
b). ________	$ ____
c). ________	$ ____
Step 2.[2/] Cost of Owners Equity: $ ____ X ____ (interest rate)	$ ____
Step 3. Taxes and Insurance: (additional)	$ 100.00
Step 4. Total Annual Ownership Costs:	$ 1700.00
Average Annual Ownership cost/acre:	$ 42.50

Section II	ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage ____ (gal.,KW) X $ ____ price + $ ____ standby charge.		$ 3/
Step 2. Repair & Maintenance Horse Power [4/] (power unit) Required ___ X Operated ___ X $ ____ per Whp/hr.		$ ____
Step 3. Repair & Maintenance: ___ % of total initial cost. (irrigation equipment Sec. 1, Step a+b+c))		$ 250.00
Step 4. Reservoir & Field Maintenance: ___ % of total initial cost.		$ ____
Step 5. Total Annual Operation & Maintenance Cost		$ 250.00
Annual Operation & Maintenance cost/acre		$ 6.25

Section III	RETURN OF INVESTMENT		Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: 2,.5T to 4.5T Hay 2 T. yield per acre increase X $60.00 per unit (bushels, pounds, tons, etc.)			$+ 120.00
Step 2. Anticipated additional Production costs per acre:	Additional Seed Water fertilizer, Chemicals and Harvesting [5/] cost (estimate)		$- 36.00
Step 3. Change in irrigation labor of 2 hours per acre[6/] X $4.00 per hour			$+ 8.00

C0689.25

C0689.25 Exhibit F (cont.)

IRRIGATION COST AND RETURN FORM

40 acres planned
4 # of irrigations

Corrugations to
Sideroll (Type of
Irrigation System Change)

Section III RETURN OF INVESTMENT	Total/Acre
Step 4. Insert annual ownership cost per acre from Section I	$- 42.50
Step 5. Insert annual operation and maintenance cost per acre from Section II:	$- 6.25
Step 6. Loss of income due to acreage out of production	$
Step 7. Cost of fuel, repair, and maintenance of of the present system on a per-acre basis.7/	$+ 8.75
Step 8. Estimated change in income per acre for the analyzed alternative:	$+ 52.00

1/ Estimated average life of system found on Table C0689.42.
12 % interest used. Use Table C0689.40.

2/ ____% interest rate for trade-in was used.

3/ See Exhibit M, Pump Irrigation Efficiencies and costs to estimate energy usage. (Gravity pressure)

4/ Estimated cost per Whp per hour found in Table C0689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table C0689.43. (May need additional fertilizer costs).

6/ Estimated average irrigation labor use per acre per irrigation may be found in table C0689.44. Reduce from .7 hrs/irrigation to .2 hrs/irr. X 4 irrigations = .5 hrs X 4 = 2 hrs.

7/ Reduced land plane ditch, clean out, gate equipment, etc. costs.

C0689.26 Exhibit G (example 1)

IRRIGATION COST AND RETURN FORM

40 acres planned
___# of irrigations

Pipeline __(Type of 7/
Irrigation System Change)

Section I ANNUAL OWNERSHIP COST	
Item	Annual Costs
Step 1.1/ Estimated cost of:	
a). Capital for Irrigation System $ 7,200 X .12750 (Amortization factor) 1300' pipeline and 10 alfalfa valves (25-yr life)	$ 918.00
b). ____________	$____
c). ____________	$____
Step 2.2/ Cost of Owners Equity: $___ X ___(interest rate)	$____
Step 3. Taxes and Insurance:	$____
Step 4. Total Annual Ownership Costs:	$ 918.00
Average Annual Ownership cost/acre:	$ 22.95

Section II ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage ____(gal.,KW) X $____price + $____ standby charge.	$ 3/
Step 2. Repair & Maintenance Horse Power 4/ (power unit) Required ___ X Operated ___X $____per Whp/hr.	$____
Step 3. Repair & Maintenance: ___% of total initial cost. (irrigation equipment Sec. 1, Step a+b+c)	$____
Step 4. Reservoir & Field Maintenance: ___% of total initial cost.	$ 72.00
Step 5. Total Annual Operation & Maintenance Cost	$ 72.00
Annual Operation & Maintenance cost/acre	$ 1.80

Section III RETURN OF INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: ____yield per acre increase X ____ per unit (bushels, pounds, tons, etc.)	$____
Step 2. Anticipated additional Production costs per acre: Additional Seed Water fertilizer, Chemicals and Harvesting 5/ cost (estimate)	$____
Step 3. Change in irrigation labor of ____ hours per acre 6/ X ____ per hour	$____

CO689.26

CO689.26 Exhibit G (cont.)

IRRIGATION COST AND RETURN FORM

40 acres planned	Pipeline (Type of 7/
____# of irrigations	Irrigation System Change)

Section III RETURN OF INVESTMENT	Total/Acre
Step 4. Insert annual ownership cost per acre from Section I	$- 22.95
Step 5. Insert annual operation and maintenance cost per acre from Section II:	$- 1.80
Step 6. Loss of income due to acreage out of production	$+ 2.00
Step 7. Cost of fuel, repair, and maintenance of of the present system on a per-acre basis. 8/	$+ 25.00
Step 8. Estimated change in income per acre for the analyzed alternative:	$+ 2.25

1/ Estimated average life of system found on Table CO689.42.
12 % interest used. Use Table CO689.40.

2/ ____% interest rate for trade-in was used.

3/ See Exhibit M, Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table CO689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table CO689.43.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table CO689.44.

7/ Portion of an irrigation system, The planned alternative is a 12" Pipeline at $4.55/ft. The unlined ditch presently there delivers adequate water.

8/ One additonal acre now used for the ditch can be irrigated. Estimated net return/acre $80/40 acres = $2.00 per acre benefit from the additional land under production.

C0689.27 Exhibit H (example 2)

IRRIGATION COST AND RETURN FORM

40 acres planned Ditch Lining (Type of[7/] Irrigation System Change)

___ # of irrigations

Section I	ANNUAL OWNERSHIP COST	
Item		Annual Costs
Step 1.[1/] Estimated cost of:		
a). Capital for Irrigation System $14,000 X 0.12750 (Amortization factor) Lined ditch and turnouts (25-yr life)		$ 1785.00
b). ________________________		$ ____
c). ________________________		$ ____
Step 2.[2/] Cost of Owners Equity: $ ___ X ___ (interest rate)		$ ____
Step 3. Taxes and Insurance:		$ ____
Step 4. Total Annual Ownership Costs:		$1785.00
Average Annual Ownership cost/acre:		$ 44.63

Section II	ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage ____ (gal.,KW) X $ ___ price + $ ____ standby charge.		$ ____ [3/]
Step 2. Repair & Maintenance Horse Power [4/] (power unit) Required __ X Operated __ X $ ____ per Whp/hr.		$ ____
Step 3. Repair & Maintenance: __ % of total initial cost. (irrigation equipment Sec. 1, Step a+b+c)		$ ____
Step 4. Reservoir & Field Maintenance: 1 % of total initial cost.		$ 140.00
Step 5. Total Annual Operation & Maintenance Cost		$ 140.00
Annual Operation & Maintenance cost/acre		$ 3.50

Section III	RETURN OF INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: ____ yield per acre increase X $ ____ per unit (bushels, pounds, tons, etc.)		$ ____
Step 2. Anticipated additional Production costs per acre:	Additional Seed Water fertilizer, Chemicals and Harvesting [5/] cost (estimate)	$ ____
Step 3. Change in irrigation labor of ___ hours per acre[6/] X ___ per hour		$ ____

CO689.27 Exhibit H (cont.)

IRRIGATION COST AND RETURN FORM

40 acres planned	Ditch Lining (Type of[7/]
___ # of irrigations	Irrigation system change)

Section III RETURN OF INVESTMENT	Total/Acre
Step 4. Insert annual ownership cost per acre from Section I	$- 44.63
Step 5. Insert annual operation and maintenance cost per acre from Section II:	$- 3.50
Step 6. Loss of income due to acreage out of production	$ ____
Step 7. Cost of fuel, repair, and maintenance of of the present system on a per-acre basis.	$+ 25.00
Step 8. Estimated change in income per acre for the analyzed alternative:	$- 23.13

1/ Estimated average life of system found on Table CO689.42.
12 % interest used. Use Table CO689.40.

2/ ___ % interest rate for trade-in was used.

3/ See Exhibit M Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table CO689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table CO689.43.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table CO689.44.

7/ Portion of an irrigation system. The planned alternative is a 12" pipelining ($10/ft). The present unlined ditch delivers adequate water.

C0689.28 Exhibit I (example 3)

IRRIGATION COST AND RETURN FORM

40 acres planned
___ # of irrigations

Ditch Cleanout (Type of[7/] Irrigation System Change)

Section I	ANNUAL OWNERSHIP COST
Item	Annual Costs
Step 1.[1/] Estimated cost of:	
a). Capital for Irrigation System \$ 3,250 X .12750 (Amortization factor) 1300' of major cleanout, shaping and siphons (25-yr life)	\$ 414.00
b). ______________	\$ ____
c). ______________	\$ ____
Step 2.[2/] Cost of Owners Equity: \$ ___ X ___ (interest rate)	\$ ____
Step 3. Taxes and Insurance:	\$ ____
Step 4. Total Annual Ownership Costs:	\$ 414.00
Average Annual Ownership cost/acre:	\$ 10.36

Section II ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage ____ (gal.,KW) X \$ ____ price + \$ ____ standby charge.	\$ ____ [3/]
Step 2. Repair & Maintenance Horse Power [4/] (power unit) Required ___ X Operated ___ X \$ ____ per Whp/hr.	\$ ____
Step 3. Repair & Maintenance: ___ % of total initial cost. (irrigation equipment Sec. 1, step a+b+c)	\$ ____
Step 4. Reservoir & Field Maintenance: ___ % of total initial cost.	\$ 260.00
Step 5. Total Annual Operation & Maintenance Cost	\$ 260.00
Annual Operation & Maintenance cost/acre	\$ 6.50

Section III RETURN OF INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: ____ yield per acre increase X \$ ____ per unit (bushels, pounds, tons, etc.)	\$ ____
Step 2. Anticipated additional Production costs per acre: Additional Seed Water fertilizer, Chemicals and Harvesting [5/] cost (estimate)	\$ ____
Step 3. Change in irrigation labor of ____ hours per acre[6/] X ____ per hour	\$ ____

C0689.28

C0689.28 Exhibit I (cont.)

IRRIGATION COST AND RETURN FORM

40 acres planned	Ditch Cleanout (Type of[7/]
____ # of irrigations	Irrigation System Change)

Section III	RETURN OF INVESTMENT	
		Total/Acre
Step 4. Insert annual ownership cost per acre from Section I		$- 10.36
Step 5. Insert annual operation and maintenance cost per acre from Section II:		$- 6.50
Step 6. Loss of income due to acreage out of production		$ ____
Step 7. Cost of fuel, repair, and maintenance of of the present system on a per-acre basis.		$+ 20.00
Step 8. Estimated change in income per acre for the analyzed alternative:		$+ 3.14

1/ Estimated average life of system found on Table C0689.42.
12 % interest used. Use Table C0689.40.

2/ ____ % interest rate for trade-in was used.

3/ See Exhibit M Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table C0689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table C0689.43.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table C0689.44.

7/ Major cleanout of the present unlined ditch. Adequate water is delivered.

C0689.29 Exhibit J (example 4)

IRRIGATION COST AND RETURN FORM

40 acres planned   Pipeline ___(Type of[7/]
___# of irrigations   Irrigation Systems Change)

Section I	ANNUAL OWNERSHIP COST	
	Item	Annual Costs
Step 1.[1/] Estimated cost of:		
a). Capital for Irrigation System $ 7,200 X.12750 (Amortization factor) 1300' of major cleanout, shaping and siphons (25-yr life).		$ 918.00
b). ______		$ ____
c). ______		$ ____
Step 2.[2/] Cost of Owners Equity: $___ X ___(interest rate)		$ ____
Step 3. Taxes and Insurance:		$ ____
Step 4. Total Annual Ownership Costs:		$ 918.00
Average Annual Ownership cost/acre:		$ 22.95

Section II	ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage _____(gal.,KW) X $____ price + $_____ standby charge.		$ ____ [3/]
Step 2. Repair & Maintenance Horse Power [4/] (power unit) Required ___ X Operated ___X $_____per Whp/hr.		$ ____
Step 3. Repair & Maintenance: ___% of total initial cost. (irrigtion equipment Sec. 1, a+b+c)		$ ____
Step 4. Reservoir & Field Maintenance: ___% of total initial cost.		$ 72.00
Step 5. Total Annual Operation & Maintenance Cost		$ 72.00
Annual Operation & Maintenance cost/acre		$ 1.80

Section III	RETURN OF INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: 20 yield per acre increase X $2.60 per unit (bushels, pounds, tons, etc.)		$ 52.00
Step 2. Anticipated additional Production costs per acre:	Additional Seed Water fertilizer, Chemicals and Harvesting [5/] cost (estimate)	$- 9.00
Step 3. Change in irrigation labor of ____ hours per acre[6/] X ____ per hour		$ ____

CO689.29

CO689.29 Exhibit J (cont.)

IRRIGATION COST AND RETURN FORM

40 acres planned	Pipeline (Type of 7/
___ # of irrigations	Irrigation System Change)

Section III	RETURN OF INVESTMENT	Total/Acre
Step 4.	Insert annual ownership cost per acre from Section I	$- 22.95
Step 5.	Insert annual operation and maintenance cost per acre from Section II:	$- 1.80
Step 6.	Loss of income due to acreage out of production 8/	$+ 2.00
Step 7.	Cost of fuel, repair, and maintenance of of the present system on a per-acre basi	$+ 25.00
Step 8.	Estimated change in income per acre for the analyzed alternative:	$+ 45.25

1/ Estimated average life of system found on Table CO689.42. 12 % interest used. Use Table CO689.40.

2/ ___ % interest rate for trade-in was used.

3/ See Exhibit M Pump Irrigation Efficiencies and costs to estimate energy usage. Used 15" of water 65%, efficiency and 300 ft. of head.

4/ Estimated cost per Whp per hour found in Table CO689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table CO689.43.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table CO689.44.

7/ Portion of an irrigation system. The planned alternative is a 12" pipelining ($4.55/ft). The unlined ditch presently there delivers inadequate water. Yield increase occurs due to decrease in seepage loss.

8/ One additional acre now used for the ditch can be irrigated. Estimated net return per acre $80/40 acres = $2.00 per acre benefit from the additional land under production.

C0689.30 Exhibit K (example 5)

IRRIGATION COST AND RETURN FORM

40 acres planned
___# of irrigations

Ditch Lining (Type of[7/] Irrigation System Change)

Section I	ANNUAL OWNERSHIP COST	
Item		Annual Costs
Step 1.[1/] Estimated cost of:		
a). Capital for Irrigation System $14,000 X .12750 (Amortization factor) Lined ditch and turnouts (25-yr life).		$ 1785.00
b). ______		$____
c). ______		$____
Step 2.[2/] Cost of Owners Equity: $___ X ___(interest rate)		$____
Step 3. Taxes and Insurance:		$____
Step 4. Total Annual Ownership Costs:		$ 1785.00
Average Annual Ownership cost/acre:		$ 44.63

Section II	ANNUAL OPERATION AND MAINTENANCE COST	Total
Step 1. Fuel: Energy usage ____(gal.,KW) X $____ price + $____ standby charge.		$____ [3/]
Step 2. Repair & Maintenance Horse Power [4/] (power unit) Required __ X Operated __ X $____ per Whp/hr.		$____
Step 3. Repair & Maintenance: __% of total initial cost. (irrigation equipment Sec. 1, a+b+c)		$____
Step 4. Reservoir & Field Maintenance: ___% of total initial cost.		$ 140.00
Step 5. Total Annual Operation & Maintenance Cost		$ 140.00
Annual Operation & Maintenance cost/acre		$ 3.50

Section III	RETURN OF INVESTMENT	Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: 20 yield per acre increase X $ 2.60 per unit (bushels, pounds, tons, etc.)		$ 52.00
Step 2. Anticipated additional Production costs per acre:	Additional Seed Water fertilizer, Chemicals and Harvesting cost (estimate)[5/]	$- 9.00
Step 3. Change in irrigation labor of ____ hours per acre[6/] X ____ per hour		$____

CO689.30 Exhibit K (cont.)

IRRIGATION COST AND RETURN FORM

40 acres planned	Ditch Lining (Type of 7/
____ # of irrigations	Irrigation System Change)

Section III RETURN OF INVESTMENT	Total/Acre
Step 4. Insert annual ownership cost per acre from Section I	$- 44.63
Step 5. Insert annual operation and maintenance cost per acre from Section II:	$- 3.50
Step 6. Loss of income due to acreage out of production	$
Step 7. Cost of fuel, repair, and maintenance of of the present system on a per-acre basis.	$+ 25.00
Step 8. Estimated change in income per acre for the analyzed alternative:	$+ 19.87

1/ Estimated average life of system found on Table CO689.42. 12 % interest used. Use Table CO689.40.

2/ ____ % interest rate for trade-in was used.

3/ See Exhibit M Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table CO689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table CO689.43. $.45/bu. x 20 bu. = $9.00.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table CO689.44.

7/ Portion of an irrigation system. The planned alaternative is a 12" pipelining ($10/ft). The present unlined ditch delivers inadequate water. Yield increase occurs due to decrease in seepage loss.

C0689.31 Exhibit L (example 6)

IRRIGATION COST AND RETURN FORM

40 acres planned
___# of irrigations

Ditch Cleanout (Type of 7/ Irrigation System Change)

Section I — ANNUAL OWNERSHIP COST

Item	Annual Costs
Step 1.[1/] Estimated cost of:	
a). Capital for Irrigation System $3,250 X .12750 (Amortization factor) Lined ditch and turnouts (25-yr life).	$ 414.00
b). ________	$ ____
c). ________	$ ____
Step 2.[2/] Cost of Owners Equity: $___ X ___(interest rate)	$ ____
Step 3. Taxes and Insurance:	$ ____
Step 4. Total Annual Ownership Costs:	$ 414.00
Average Annual Ownership cost/acre:	$ 10.36

Section II — ANNUAL OPERATION AND MAINTENANCE COST

	Total
Step 1. Fuel: Energy usage _____(gal.,KW) X $____ price + $_____ standby charge.	$ ____ 3/
Step 2. Repair & Maintenance Horse Power 4/ (power unit) Required ___ X Operated ___X $_____per Whp/hr.	$ ____
Step 3. Repair & Maintenance: ___% of total initial cost. (irrigation equipment Sec. 1, a+b+c)	$ ____
Step 4. Reservoir & Field Maintenance: ___% of total initial cost.	$ 260.00
Step 5. Total Annual Operation & Maintenance Cost	$ 260.00
Annual Operation & Maintenance cost/acre	$ 6.50

Section III — RETURN OF INVESTMENT

		Total/Acre
Step 1. Value per acre of expected increase from irrigation system being analyzed: 5 yield per acre increase X $ 2.60 per unit (bushels, pounds, tons, etc.)		$+ 13.00
Step 2. Anticipated additional Production costs per acre:	Additional Seed Water fertilizer, Chemicals and Harvesting cost (estimate)5/	$- 2.25
Step 3. Change in irrigation labor of ____ hours per acre[6/] X ____ per hour		$ ____

CO689.31

CO689.31 Exhibit L (cont.)

IRRIGATION COST AND RETURN FORM

40 acres planned	Ditch Cleanout (Type of 7/
____ # of irrigations	Irrigation System Change)

Section III RETURN OF INVESTMENT	Total/Acre
Step 4. Insert annual ownership cost per acre from Section I	$- 10.30
Step 5. Insert annual operation and maintenance cost per acre from Section II:	$- 6.50
Step 6. Loss of income due to acreage out of production	$
Step 7. Cost of fuel, repair, and maintenance of of the present system on a per-acre basis.	$+ 20.00
Step 8. Estimated change in income per acre for the analyzed alternative:	$+ 13.95

1/ Estimated average life of system found on Table CO689.42. 12 % interest used. Use Table CO689.40.

2/ ____ % interest rate for trade-in was used.

3/ See Exhibit M Pump Irrigation Efficiencies and costs to estimate energy usage.

4/ Estimated cost per Whp per hour found in Table CO689.41.

5/ Changes in harvesting costs due to yield changes may be found in Table CO689.43. $.45/bu. x 5 bu. = $2.25.

6/ Estimated average irrigation labor use per acre per irrigation may be found in table CO689.44.

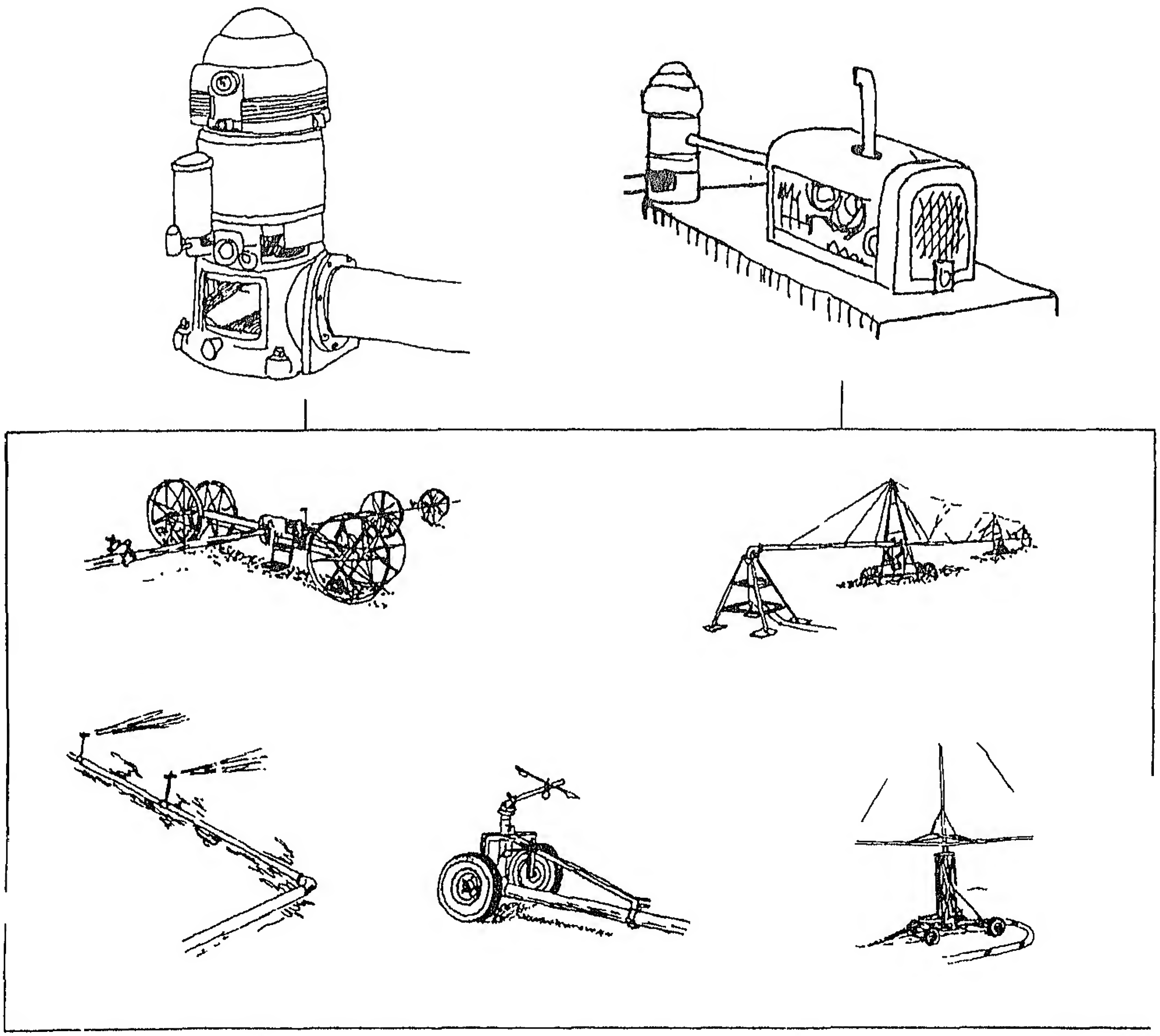
7/ Major cleanout of the present unlined ditch. Inadequate water is delivered.

C0689.32 Exhibit M, Pump Irrigation Efficiencies and Costs

This exhibit consists of a paper published by the Agricultural Extension Service, University of Wyoming, March 1981, B-740, titled Pump Irrigations Efficiencies and Costs.

PUMP IRRIGATION EFFICIENCIES AND COSTS

Agricultural Extension Service
University of Wyoming
March 1981
B-740



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2-81/1M/.41

Contents

PUMP IRRIGATION EFFICIENCIES AND COSTS

by

Donald J. Brosz*
Extension Irrigation Engineer

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INTRODUCTION

The ever increasing cost of energy has many pump irrigators concerned. They are asking questions about keeping costs at a minimum. Predictions are that electrical costs to the customer will be 13¢ per kilowatt-hour by the early 1990's from the present rate of approximately 4¢ per kilowatt-hour. Similar increases in costs of diesel, natural gas, propane and gasoline are predicted. Thus, it is becoming increasingly important that pump irrigators keep their pumping plants operating efficiently and apply the appropriate quantity of water to the land as efficiently as possible.

Through many years of field studies of irrigation pumping plant efficiencies, it has been found that many pumping plants operate below potential efficiency. When to repair or replace the existing pumping plant depends upon the repair or replacement costs versus the decreased costs (due to the improved pumping plant efficiency).

The pump irrigator today will need to give more attention also to the efficiency of irrigation water application. Worn nozzles, over-irrigation, irrigating

*/ The authors want to acknowledge Sue Lowry, a student in Agricultural Economics for her assistance in gathering and analyzing data presented in this publication.

at the wrong time and wrong nozzle sizes - all contribute to inefficient irrigation and extra cost of applying water.

RECORDS ON PUMPING PLANT

A pump irrigator will need to keep some pumping plant and water records as a guide for efficient management and operation of the irrigation system. These records should include (1) distance pump lifts the water from water surface to discharge side of the pump; (2) the pressure the pump is developing; (3) the quantity of water being pumped; (4) the total energy being used; and (5) the daily hours the system is in operation.

Figure 1 is an example of an operating irrigation pumping plant. The reader may use this example as a guide to making measurements on the pumping plant.

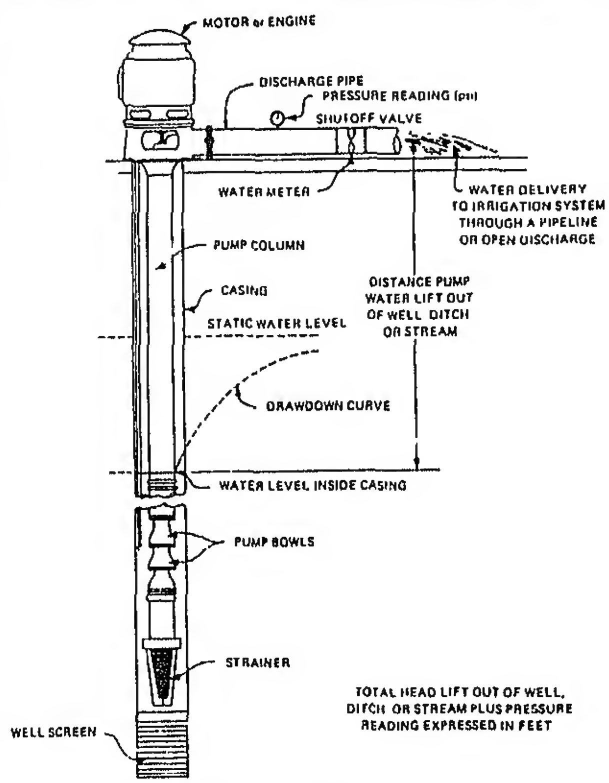

FIGURE 1 IRRIGATION PUMPING PLANT

The total pumping plant work includes two basic measurements: 1) measuring the distance the water is being lifted on the suction side of the pump and; 2) measuring the pressure the pump produces on the discharge side of the pump.

The distance water is lifted from the well, stream or reservoir water surface to the pump discharge pipe (Figure 1) is measured in feet. The distance the water is lifted to the pump discharge should be measured while the pump is operating as shown in the above figure. Lift in a well can be measured using a water level indicator meter (several irrigators may want to get together and purchase such a meter). A water level indicator meter may also be leased from a well driller or irrigation equipment supplier. It is suggested where a well is used, a measurement of depth to water while pumping should be made about once a month. Those using surface water should peroidically note if surface water levels drop during the season, and record in feet the distance that water is lifted by the pump.

Pressure on the discharge side of the pump can be measured with a pressure gauge (Figure 1). A good quality pressure gauge should be used. The pressure gauge reading is in pounds per square inch (psi) and can be converted to feet by multiplying the reading by 2.31. For example, a pressure reading of 100 psi is equal to 231 feet (100 x 2.31), or 70 psi is the same as 162 feet (70 x 2.31).

The total work the pumping plant is doing (often expressed as total head) is the sum of the distance water is lifted plus pressure at the discharge side of the pump, both expressed in feet. Thus, if the water is lifted from a well 147 feet and the discharge pressure is 162 feet (70 psi), then the total work or head is 309 feet (147 + 162). There also is some friction loss in the suction pipe or pump column that should be added to the total pump work. A simplified procedure for analyzing a pumping plant is to omit this negligible friction amount.

The quantity of water being pumped can be measured by installing a water meter on the discharge side of the pump (Figure 1). A water meter can be purchased that shows the gallons per minute (gpm). Most water meters also total the quantity of water. Meters are available that total either in gallons, acre-inches or acre-feet. Weekly readings should be taken of the quantity of water being pumped and the hours the irrigation system was operated. Any changes in the gpm's being pumped can indicate a change within the irrigation system.

Electrical energy records can be taken from the watthour meter quickly and simply. Typical electrically powered irrigation units feature watthour meters near the pump motor or on the power pole. Kilowatt hours (KWH) can be determined by taking readings from the dials as shown at the top portion of the watthour meter (Figure 2).

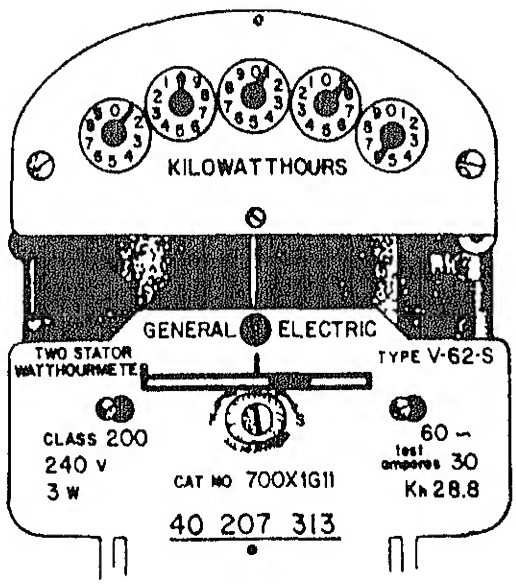

Figure 2. Watthour Meter

A reading can be taken and compared to another reading several hours or a day later. To determine KWH, read left to right and then back to the smallest number. The above reading is 10085. Assume another reading taken 24 hours later shows 12005. A total of 1920 KWH's have been used during that period of time (12005-10085). If the irrigation pumping plant had operated without stopping during this 24 hour period, then an average of 80 KWH's would have been used each hour (1920÷24).

KWH can be converted to horsepower (HP) by the following formula: HP = 1.34 x KWH. For the above example, HP is 107 (1.34 x 80).

KWH readings can also be made by timing the revolutions of the meter disk. Procedures for this are outlined in publication B-654, "Horsepower Determinations From Watthour Meters." This publication is available through your county extension office.

A power company may install a current transformer ahead of the watthour meter. Current transformers are devices used to move only a proportion of the current through the meter. Check with someone from your power company if a current transformer is used, and have them provide the multiplier to obtain the actual reading of KWH used. Power company personnel can provide the multiplier number and/or obtain accurate KWH readings from the watthour meter.

Natural gas readings are taken from similar type meters and read the same as electrical meters. Again, the meter may have a multiplier factor. Work with people from the gas company on procedures for obtaining accurate readings. Other fuels such as diesel, gasoline and propane can be measured by the quantity replaced in the tank and a record kept of operation hours.

Keeping records of the amount of time the irrigation system is in operation is essential for several reasons. Time is used for calculating kilowatt hours used per hour and determination of the quantity of water applied per irrigation or any other specified time. Quantity of irrigation water applied is

calculated by the following procedure: four-hundred and fifty (450) GPM is the same as 1 cubic foot per second, equal to 1 acre-inch of water per hour. If the system operates a total of 24 hours a day, each 450 GPM is equal to 24 acre-inches or 2 acre-feet of water. Assume an irrigation system is pumping 800 GPM. The acre-feet of water pumped per 24 hours equals 3.6 $\left(\frac{800}{450} \times 2\right)$ equal to 43.2 acre-inches of water (3.6x12). An acre-inch of water is 1 inch of water on 1 acre, or an acre-foot of water is 1 foot of water on 1 acre. Assuming 20 acres were irrigated with the above 43.2 acre-inches, 2.16 inches were pumped for each acre (43.2÷20).

PUMPING PERFORMANCE

The above measurements can be used to determine the performance of the pumping unit with the following formula.

$$\text{Performance} = \frac{22{,}600 \times (\text{KWH, MCF or gallons})}{\text{GPM} \times \text{Total Head}}$$

Where:

22,600 = a constant conversion factor (based on an acre-foot of water pumped [gross] per 100 foot of head for a 24 hour period).

KWH = kilowatt hours of electricity
MCF = thousand cubic feet of natural gas
gallons of diesel, gasoline or propane
(Used in 24 hours. Period of time that the irrigation system was in operation.)

GPM = pumping rate in gallons per minute

Total Head = distance water is lifted out of well, stream or reservoir + psi (2.31)

The above formula gives KWH of electricity, MCF of natural gas or gallons of diesel, gasoline or propane being used in a 24 hour period per acre-foot of water (being pumped per 100 feet of head). Top performance values for new or repaired (efficient) pumping plants are given below.

Electric . . . . . 150 KWH/acre-foot/100 feet of head (based on 1 kilowatt hour per 1.34 horsepower and 68% pumping plant efficiency).

Natural Gas. . . . 1.9 MCF/acre-foot/100 feet of head (based on 900,000 BUT's per 1000 cubic feet of gas and 20% pumping plant efficiency). BTU's can vary substantially in natural gas so check with gas supplier to see if BTU's are much different than above.

Diesel . . . . . . 12 Gallons/acre-foot/100 feet of head (based on 138,800 BTU's per gallon of diesel and 21% pumping plant efficiency).

Pumping plant efficiency includes the combined efficiency of the irrigation pump and the power unit. Attainable field efficiencies should be about 68% for electric driven irrigation pumping plants, 20% for natural gas and 21% for diesel. The overall efficiency of the internal combustion engine units is lower than electric units because of the performance of each unit. You should compare efficiency and cost of operation.

CALCULATING PUMPING COSTS

The following examples compare the energy costs of an existing system with the performance of a new or repaired (efficient) pumping plant.[a/]

Electricity

Data for existing system:

Difference between meter readings for a 24 hour period = 2160

Total Head (ft) = 275

Discharge (GPM) = 900

$$\text{Performance} = \frac{22{,}600 \times 2160}{900 \times 275} = 197.2 \text{ KWH/acre-foot/100 feet of head.}$$

Energy Cost @ $.04/KWH

197.2 x .04 = $7.89/acre-foot/100 feet of head

[a/] The pumping costs under alternative pumping plant efficiencies can also be estimated from a computer program called PUMP in the AGNET System. An explanation of how the PUMP program can be used is found in Appendix B, page 17.

Top Performance

150 KWH x $.04 = $6.00/acre-foot/100 feet of head

Energy Cost Savings

$7.89-$6.00 = $1.89/acre-foot/100 feet of head

The energy cost for pumping one acre-foot of water (per 100 feet of head) for electricity for various pumping plant efficiencies and electrical rates is shown in Table 1.

Natural Gas

Data for Existing System:

Difference in meter readings for a 24 hour period	= 31 MCF
Total Head (ft)	= 275
Discharge (GPM)	= 900

$$\text{Performance} = \frac{22,600 \times 31}{900 \times 275} = 2.83 \text{ MCF/acre-foot/100 feet of head}$$

Energy cost @ $1.60/MCF

2.83 MCF x $1.60 = $4.53/acre-feet/100 feet of head

Top Performance

1.9 MCF x $1.60 = $3.04/acre-feet/100 feet of head

Energy Savings

$4.53-$3.04 = $1.49/acre-feet/100 feet of head

The cost of natural gas to pump one acre-foot of water (per 100 feet of head) for various pumping plant efficiencies and natural gas rates is shown in Table 2.

Diesel

Data for Existing System:

Tank refill after 24 hour period	= 160 gallons
Total Head (ft)	= 275
Discharge (GPM)	= 900

Table 1. THE EFFECT OF EFFICIENCY ON POWER COSTS FOR ELECTRICALLY POWERED PUMPING PLANTS TO PUMP ONE ACRE-FOOT OF WATER AGAINST 100 FOOT OF HEAD.

Pumping Plant Efficiency (Percent)	Consumption (kilowatt Hours/acre-foot/100 feet)	Cost/Acre-foot/100 foot of Head ($)											
		1¢/KWH	2¢/KWH	3¢/KWH	4¢/KWH	5¢/KWH	6¢/KWH	7¢/KWH	8¢/KWH	9¢/KWH	10¢/KWH	11¢/KWH	12¢/KWH
70	146	1.46	2.92	4.39	5.85	7.31	8.77	10.24	11.70	13.16	14.62	16.09	17.55
65	157	1.57	3.15	4.72	6.30	7.87	9.45	11.02	12.60	14.17	15.75	17.32	18.90
60	171	1.71	3.41	5.12	6.82	8.53	10.24	11.94	13.65	15.36	17.06	18.77	20.47
55	186	1.86	3.72	5.58	7.45	9.31	11.17	13.03	14.89	16.75	18.61	20.47	22.34
50	205	2.05	4.00	6.14	8.19	10.24	12.28	14.33	16.38	18.43	20.47	22.52	24.57
45	227	2.27	4.55	6.82	9.10	11.37	13.65	15.92	18.20	20.47	22.75	25.02	27.30
40	256	2.56	5.12	7.68	10.24	12.80	15.36	17.92	20.47	23.03	25.59	28.15	30.71
35	292	2.92	5.85	8.77	11.70	14.62	17.55	20.47	23.40	26.32	29.25	32.17	35.10
30	341	3.41	6.82	10.24	13.65	17.06	20.47	23.89	27.30	30.71	34.12	37.54	40.95
25	409	4.09	8.19	12.28	16.38	20.47	24.57	28.66	32.76	36.85	40.95	45.04	49.14
20	512	5.12	10.24	15.36	20.47	25.59	30.71	35.83	40.95	46.07	51.18	56.03	61.42
15	682	6.82	13.65	20.47	27.30	34.12	40.95	47.77	54.60	61.42	68.25	75.07	81.90
10	1024	10.24	20.47	30.71	40.95	51.18	61.42	71.66	81.90	92.13	102.37	112.61	122.84
5	2047	20.47	40.95	61.42	81.90	102.37	122.84	143.32	163.79	184.27	204.74	225.21	245.69

Table 2. THE EFFECT OF EFFICIENCY ON POWER COSTS FOR NATURAL GAS POWERED PUMPING PLANTS TO PUMP ONE ACRE-FOOT OF WATER AGAINST 100 FOOT OF HEAD. (Assume BTU content of natural gas as 900,000 BTU'S per 1000 Cubic feet of gas [mcf].)

Pumping Plant Efficiency (Percent)	Consumption (MCF/acre-foot/100 foot)	Cost/Acre-foot/100 foot of Head ($)											
		$1.00 /MCF	$1.25 /MCF	$1.50 /MCF	$1.75 /MCF	$2.00 /MCF	$2.25 /MCF	$2.50 /MCF	$2.75 /MCF	$3.00 /MCF	$3.25 /MCF	$3.50 /MCF	$4.00 /MCF
20	1.94	1.94	2.43	2.91	3.40	3.88	4.37	4.85	5.34	5.82	6.31	6.79	7.76
18	2.16	2.16	2.70	3.23	3.77	4.31	4.85	5.39	5.93	6.47	7.01	7.55	8.62
16	2.43	2.43	3.03	3.64	4.24	4.85	5.46	6.06	6.67	7.28	7.88	8.49	9.70
15	2.59	2.59	3.23	3.88	4.53	5.17	5.82	6.47	7.11	7.76	8.41	9.05	10.35
14	2.77	2.77	3.46	4.16	4.85	5.54	6.23	6.93	7.62	8.31	9.01	9.70	11.08
13	2.99	2.99	3.73	4.48	5.22	5.97	6.72	7.46	8.21	8.96	9.70	10.45	11.94
12	3.23	3.23	4.04	4.85	5.66	6.47	7.27	8.08	8.89	9.70	10.51	11.32	12.93
11	3.53	3.53	4.41	5.29	6.17	7.05	7.94	8.82	9.70	10.58	11.46	12.34	14.11
10	3.88	3.88	4.85	5.82	6.79	7.76	8.73	9.70	10.67	11.64	12.61	13.58	15.52
9	4.31	4.31	5.39	6.47	7.54	8.62	9.70	10.78	11.86	12.93	14.01	15.09	17.24
8	4.85	4.85	6.06	7.28	8.49	9.70	10.91	12.13	13.34	14.55	15.76	16.98	19.40
6	6.47	6.47	8.08	9.70	11.32	12.93	14.55	16.17	17.78	19.40	21.02	22.63	25.87
4	9.70	9.70	12.13	14.55	16.98	19.40	21.83	24.25	26.68	29.10	31.53	33.95	38.60
2	19.40	19.40	24.25	29.10	33.95	38.80	43.65	48.50	53.35	58.20	63.05	67.90	77.60

$$\text{Performance} = \frac{22{,}600 \times 160}{900 \times 275} = 14.6 \text{ gal./acre-foot/100 feet of head}$$

Energy Cost @ $1.05/gal

14.6 gal x $1.05 = $15.34/acre-foot/100 feet of head

Top Performance

12 gal x $1.05 = $12.60/acre-foot/100 feet of head

Energy Savings

$15.34-$12.60 = $2.74/acre-foot/100 feet of head

The diesel cost to pump an acre-foot of water (per 100 feet of head) for various pumping plant efficiencies, and dollars per gallon, is shown in Table 3. Tables 1-3 show the cost of energy to pump an acre-foot of water (per 100 feet of head) at various pumping plant efficiencies. Very few pumping plants in Wyoming are powered by gasoline and propane units. If information is needed on these units, it can be supplied by the authors. C/O College of Agriculture, University of Wyoming.

When considering annual energy costs for irrigation, you will find that energy savings can be quite substantial. For instance, when applying 2 acre-feet of water per acre (gross) to a 130 acre field, with electricity as a source of energy, the savings for the above example would equal $1,351 for one year:

i.e. $1.89 energy savings x 2 acre-feet x 130 acres x 2.75 (275 feet of head) = $1,351.

As energy costs continue to rise, it is even more crucial to keep your pumping plant and irrigation system running as efficiently as possible to minimize annual irrigation expenses.

ENERGY SAVINGS VS. PUMP REPAIR COSTS

How can an irrigator use the above information to estimate his pumping plant's efficiency and to decide whether or not to repair that plant? Using the per-

Table 3. THE EFFECT OF EFFICIENCY ON POWER COSTS FOR DIESEL POWERED PUMPING PLANTS TO PUMP ONE ACRE-FOOT OF WATER AGAINST 100 FOOT OF HEAD.

Pumping Plant Efficiency (Percent)	Consumption (Gallons/ Acre-foot/ 100 feet of head)	Cost/acre-foot/100 foot of Head ($) $0.90 /Gal	$1.00 /Gal	$1.10 /Gal	$1.20 /Gal	$1.30 /Gal	$1.40 /Gal	$1.50 /Gal	$1.60 /Gal	$1.70 /Gal	$1.80 /Gal	$1.90 /Gal	$2.00 /Gal
22	11.4	10.26	11.40	12.54	13.68	14.82	15.96	17.10	18.24	19.38	20.52	21.66	22.80
20	12.5	11.25	12.50	13.75	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75	25.00
18	13.9	12.51	13.90	15.29	16.68	18.07	19.46	20.85	22.24	23.63	25.02	26.41	27.80
17	14.7	13.23	14.70	16.17	17.64	19.11	20.58	22.05	23.52	24.99	26.46	27.93	29.40
16	15.6	14.04	15.60	17.16	18.72	20.28	21.84	23.40	24.96	26.52	28.08	29.64	31.20
15	16.7	15.03	16.70	18.37	20.04	21.71	23.38	25.05	26.72	28.39	30.06	31.73	33.40
14	17.9	16.11	17.90	19.69	21.48	23.27	25.06	26.85	28.64	30.43	32.22	34.01	35.80
13	19.2	17.28	19.20	21.12	23.04	24.96	26.88	28.80	30.72	32.64	34.56	36.48	38.40
12	20.8	18.72	20.80	22.88	24.96	27.04	29.12	31.20	33.28	35.36	37.44	39.52	41.60
11	22.7	20.43	22.70	24.97	27.24	29.51	31.78	34.05	36.32	38.59	40.86	43.13	45.40
10	25.0	22.50	25.00	27.50	30.00	32.50	35.00	37.50	40.00	42.50	45.00	47.50	50.00
9	27.8	25.02	27.80	30.58	33.36	36.14	38.92	41.70	44.48	47.26	50.04	52.82	55.60
8	31.3	28.17	31.30	34.43	37.56	40.69	43.82	46.95	50.08	53.21	56.34	59.47	62.60
6	41.7	37.52	41.70	45.87	50.04	54.21	58.38	62.55	66.72	70.89	75.05	79.23	83.40
4	62.5	56.25	62.50	68.75	75.00	81.25	87.50	93.75	100.00	106.25	112.50	118.75	125.00
2	125.0	112.50	125.00	137.50	150.00	162.50	175.00	187.50	200.00	212.50	225.00	237.50	250.00

formance formula discussed earlier, estimates can be made of the power savings that might be expected. The annual energy cost savings (with an efficient pumping plant) should be compared with the cost of pump repairs over the expected life of the repairs.

An example illustrating how the energy savings from pump repairs can be estimated is given below. In reviewing the records kept on your center pivot system, you obtain the following data:

24 hour difference in meter readings	= 2668 KWH
Distance water is lifted out of well	= 195 ft
psi	= 85
Total Head (195 + 85 [2.31])	= 391 ft
Discharge	= 915 GPM

Using the performance formula presented earlier:

$$\text{Performance} = \frac{\text{22,600xKWH (energy used in 24 hours)}}{\text{GPMxTotal Head}}$$

$$= \frac{22{,}600\text{x}2668}{915\text{x}391} = 168 \text{ KWH/acre-foot/100 feet of head}$$

(Table 1.) The pumping plant is operating at about 60 percent efficiency. At 60% efficiency and power at 4¢/KWH, (using Table 1) it shows the cost as $6.82 to pump an acre-foot for each 100 feet of head. This results (with a head of 391 feet) in a cost of $26.67 per acre-foot of water pumped ($6.82 x 3.91) Operating at 65% efficiency and power at 4¢/KWH this same system would cost $6.30 to pump an acre-foot of water for each 100 feet of head (Table 1). The energy cost per acre-foot of water pumped (with a head of 391 feet) would be $24.63 ($6.30x3.91). Therefore, improving the pumping plant efficiency from 60 to 65% with power at 4¢/KWH results in an estimated energy savings of $2.04 ($26.67-$24.63) per acre-foot of water pumped. If 2 acre-feet of water per acre are pumped, and 128 acres irrigated, the total annual energy savings would

be $522 ($2.04 x 2 acre-feetx128 acres).

The above energy savings is for the system and power costs specified above. To estimate the energy savings on your system, you need to substitute your own information. Once this information is available you can use the same procedure used above to estimate your annual energy savings. Compare the estimated energy savings with the cost of making the needed pumping plant repairs. In comparing remember that the power saving estimate is an annual saving while your repair costs are an improvement figured over a number of years. Therefore, you should compare the estimated energy savings over the life of the repair job with the repair cost. For example, if the repair is expected to last 5 years, total energy savings over this period would be $2,610 ($522x5 years). Of course, this estimate does not include power cost increases. Annual savings would increase in ratio to power cost increases. The expected increase in the price of power could be incorporated into your energy savings estimate over the life of the repairs. Compare the energy savings with the estimated cost of the repair obtained from a local irrigation supplier.

SUMMARY

Using the performance formula and tables in this publication you can estimate very closely if your irrigation pumping plant is operating efficiently. As energy costs increase it becomes more and more important that pump irrigators maintain their pumping plant at an efficient operating level, holding irrigation costs to a minimum. Following the procedures outlined in this publication you can evaluate each of your respective irrigation pumping plants.

Appendix

Terms and Formula's

PUMPING PLANT EFFICIENCY: The efficiency of an irrigation pumping plant is the combined efficiency of the pump and the power unit. No pumping plant is 100% efficient as energy is lost within the power unit and in the pump. Energy required for an efficient pumping plant to pump an acre-foot of water against a 100 ft. of head for a 24 hour period are:

Electric:	150 KWH/acre-foot/100 feet of head/24 hours
Natural Gas:	1.9 MCF/acre-foot/100 feet of head/24 hours
Diesel:	12 Gallons/acre-foot/100 feet of head/24 hours

Feet of Head = Lift in feet + PSI (2.31)

PUMPING PERFORMANCE FORMULA: Energy used per acre-foot of water pumped against a 100 feet of head for a 24 hour period can be obtained from the formula below:

$$\text{Performance (energy consumed)} = \frac{22{,}600 \text{ X (KWH, MCF or gallons)}}{\text{GPM X Total Head in Feet}}$$

ENERGY COSTS OF PUMPING:

Energy costs to pump one acre-foot against 100 ft. of head for 24 hours can be estimated using the formulas below:

Energy cost = $/unit of energy X Pumping Performance

Electric:	$/KWH X KWH/acre-foot/100 feet of head
Natural Gas:	$/MCF X MCF/acre-foot/100 feet of head
Diesel:	$/Gallon X Gallons/acre-foot/100 feet of head

ANNUAL ENERGY COSTS FOR IRRIGATION SYSTEM: The formula below gives an estimate of the annual energy costs for a particular irrigation system.

Annual Energy costs = $/unit of energy X
Units of Energy/acre-foot/100 feet of head
X feet of head in hundreds X acre-feet/acre
X acres irrigated

Example: Power source: Electric

$/unit of energy:	.04/KWH
Energy/acre-foot/100 feet of head:	168 KWH
350 feet of head in hundreds:	3.5
Acre-feet per acre:	2
Acres irrigated:	130

Annual Energy Costs = .04 X 168 X 3.5
X 2 X 130 = $6,115

ACRE-FOOT: This is the quantity of water that covers one acre a foot deep. This is approximately 326,000 gallons or a flow of 450 GPM or 1 cfs for 12 hours.

ACRE-INCH: This is the quantity of water that covers one acre an inch deep. This is approximately 27,000 gallons.

CFS: This is a flow of water which is equal to 450 gpm or 1 acre-inch of water per hour.

Appendix B

AGNET's Computer Program PUMP

PUMP, a computer program, is available to irrigators through AGNET. It analyzes the costs of owning and operating a particular irrigation system. The data required to use PUMP are listed below under Input Data. In addition to those data, there are a number of default values listed in the computer program PUMP. These default values will be used unless you change these (values) to fit your irrigation system. For example, you know from your records the electricity consumption, hours of operation and quantity of water pumped. Using these records and the information in Table 1, you determine your pumping plant efficiency to be 59%. The default value related to pumping plant efficiency in the PUMP program is % of Nebraska Standards, which is assumed to be 100%. The 100% of Nebraska Standards for electric systems is based on a pumping plant efficiency of 66%. Since your pumping plant efficiency is less than 66%, you would adjust the percentage of Nebraska standard to that determined by the ratio of 59%/66% or 89% of Nebraska Standards.

An estimate of the effect of pumping plant efficiency on energy costs, is obtained by running the PUMP program at 100% of Nebraska Standards and at 89% of Nebraska Standards. Then figure the difference in energy costs for the two runs. By knowing the efficiency of your pumping plant and adjusting the percentage of Nebraska Standards, you can estimate your expected savings in fuel cost if you decide to repair your pumping plant. These fuel cost savings (over the estimated life of the repair) should then be compared with the cost of making the pumping plant repairs. If the cost savings over the life of the repair exceeds the repair cost, this suggests that repairs are needed for the pumping plant.

IRRIGATION SYSTEM COST ANALYSIS

	Example System	Your Existing System	Your Repaired System
I. Input Data			
1. GPM	900		
2. Lift (ft.)	100		
3. PSI	75		
4. Acres	130		
5. Inches applied/year (net or gross)	20 Net		
6. Energy source	Electric		
7. Energy cost			
A) $/kw-hr	.03		
B) Annual connect charge ($/hp)	10		
II. Default Values			
1. Interest rate (#10)	10%		
2. Pump Eff. (#12)	75%		
3. % of Nebraska Standards (#18)	100%		
4. System Eff. (#20)	80%		
5. Fuel Inflation (%/yr) (#22)	8		
III. Results:			
Annual Costs			
1. Fixed cost	$ 6,710		
2. Fuel cost	3,421		
3. Operating cost	3,547		
4. Total cost	13,678		
5. 1st yr. cost/ac	105		
6. 15 yr. ave. cost/ac	135		

SUBPART D - TABLES

Table C0689.40 Amortization Factors

Expected No. of Years of Life	8%	9%	10%	11%	12%	13%	14%	15%
2	.56077	.56847	.57619	.58393	.59170	.59948	.60729	.61512
4	.30192	.30867	.31547	.32233	.32923	.33619	.34320	.35027
6	.21632	.22292	.22961	.23638	.24323	.25015	.25716	.26424
8	.17401	.18067	.18744	.19432	.20130	.20839	.21557	.22285
10	.14903	.15582	.16275	.16980	.17698	.18429	.19171	.19925
12	.13270	.13965	.14676	.15403	.16144	.16899	.17667	.18448
15	.11683	.12406	.13147	.13907	.14682	.15474	.16281	.17102
20	.10185	.10955	.11746	.12558	.13388	.14235	.15099	.15976
25	.09368	.10181	.11017	.11874	.12750	.13643	.14550	.15470

Amortization - method to convert costs into equal annual payments.

C0689.41 Cost of Repair and Maintenance

Type of Power Unit	Cost per Whp per hour	
Electric motor and controls	$	0
Gasoline	$	.0030
Diesel	$	.0027
Propane	$	.0020
Natural Gas	$	.0020

Table C0689.42 Estimated Life Expectancy of Systems[1/]

Item	Expected Life[2/] (yrs)	(hrs)
Irrigation systems		
Center pivot	10-14	
Side roll	15-20	
Drip	20	
Solid set	20	
Big gun	10	
Ditches (Earthen needs greater maintenance)	25	
Well casing	20	
Power unit		
Propane, natural gas and diesel	14	28,000
Water-cooled gas	9	18,000
Electric	25 +	50,000
Reservoir	25 +	
Pipelines		
Aluminum	15	
Galvanized steel	15	
Plastic	20-25	
Concrete	20-25	
Gated	10	
Miscellaneous		
Valves	12	
Measuring devices	12	
Automation equipment	12	
Pipe trailers	15	
Sprinkler heads	8	
Pump, turbine		
Bowl (about 50% of cost of pump unit)	8	16,000
Column, etc.	16	32,000
Pump, centrifugal	16	32,000
Power transmission		
Gear head	15	30,000
V-belt	3	6,000
Flat belt, rubber and fabric	5	10,000
Flat belt, leather	10	20,000

1/ Estimate average life expectancy. They are averages and may change for particular situations. Equipment may have a lesser life when animal wastes are used.

2/ Section 300.3 of the Economics Handbook may also be helpful.

Table C0689.43 Estimated Average Change in Harvest Costs Due to Yield Changes

	Yield Change (Units)	Corresponding Change in Harvest Cost
wheat	1 bu.	$ .35
barley	1 bu.	.35
corn	1 bu.	.45
grain sorghum	1 Cwt.	.50
alfalfa	1 ton	18.00
hay	1 ton	18.00
beans	1 Cwt.	1.10
apples	1 bu.	2.50

This table may be helpful in Step 2 of Section III of the Irrigation Cost and Return Form. Preharvest production costs (excluding irrigation labor, irrigation fuel cost, and irrigation repair and maintenance) generally change very little when comparing one type of irrigation system to another. However, the estimated harvest costs will change nearly proportional with changes in yield. Changes in harvest costs include: hauling, storage, drying, spoilage, marketing, shrinkage, twine, additional harvest labor packing charges, etc. For an example, estimated increase in apple yields of 80 bushels will occur by changing from furrow to automated furrow irrigation. The increase in harvest costs would be 80 bu. x $2.50 = $200.00. See Exhibit E for other examples of table being used.

Table C0689.44 Average Labor Required for Various Irrigation Systems

Type of System	Required	Average Labor Required
	(hrs. per acre per irrigation)	(hrs per acre per irrigation)
Hand moved:		
Portable set	0.50-1.50	1.00
Solid Set	0.20-0.50	.35
Tractor moved:		
Skid-mounted	0.20-0.40	.30
Wheel-mounted	0.20-0.40	.30
Self moved:		
Side-wheel-roll	0.10-0.30	.20
Side move	0.20-0.30	.20
Self-propelled:		
Center-pivot	0.05-0.15	.10
Side-move	0.05-0.15	.10
Single-Sprinkler:		
Hand-moved	0.50-1.50	1.00
Self-propelled	0.10-0.30	.20
Boom-sprinkler:		
Tractor-moved	0.20-0.50	.35
Self-propelled	0.10-0.30	.30
Permanent:		
Manual or Automatic	0.05-0.10	.075
Drip	0.05-0.15	.10
Automated furrow	.05-.15	.10
Level border (Automated)	.05-.15	.10
Level Furrow	0.10-0.50	.30
Graded:		
Graded border	0.20-1.0	.60
Contour ditch	1.00-2.0	1.50
Grade furrow	0.40-1.2	.75
Corrugation	0.40-1.2	.75
Contour Furrow	0.50-1.5	1.00

TABLE OF CONTENTS

Part 690 - Use of Water Supply Forecasts

Part 690 - Use of Water Supply Forecasts

SUBPART A - GENERAL

C0690.10 Purpose of forecasts.

(a) Snow surveys and water supply forecasts provide information from which advance estimates are made of available surface waters to meet the demands of the irrigated area. Chief use of water supply forecasts in agriculture is to adjust irrigation demand to the available water supply.

(b) Water supply forecasts are very well suited to areas with and without stored water supply. These allow farmers to plan when and how to use the projected quantity of water that will be available for their use. It is a matter of determining whether:

(1) the irrigated acreage should be cut back;

(2) to extend the limited water supply over all the acreage, thereby reducing the number of irrigations and reducing yields (planned deficit irrigation);

(3) to postpone the seeding of some land;

(4) to irrigate best or highest productive fields;

(5) to improve delivery system; and/or

(6) to supplement supply with wells.

C0690.11 Planning principles.

(a) Generally, more efficient use of stored water is achieved by using an adequate supply of water on a limited acreage than by spreading a short water supply over all available acreage.

(b) If water supply is expected to be less than normal:

(1) Perennial hay crops should be allotted a reasonable amount of water early in the season to produce a good first cutting.

(2) Priority in the use of water should go to the best fields and especially those most efficiently irrigated.

(3) The farmer must decide, in line with economic benefits and management constraints, the proportion of acreage to plant in high water-using and more profitable crops in relation to the low water-using crops and fallow.

(4) Special attention should be given to improving the efficiency of the irrigation system and the distribution system.

(5) Consideration should be given to seasonal needs and growth characteristics of plants in relation to water availability.

(6) Livestock numbers may need to be reduced in anticipation of feed shortages.

(c) If water supply is expected to exceed the normal demand:

(1) More heavy water-using crops may be planted.

(2) Leaching of salts from the soil may be accomplished.

(3) Water can remain in storage for future use. Cooperative agreements for carry-over storage should be worked out among the water users.

(4) Apply deep, late-season irrigations to utilize the storage capacity of the soil.

CO690.12 Forecast data.

(a) In the water supply forecast bulletins published by the Soil Conservation Service, the stream flow forecast is stated in terms of the number of acre-feet that will flow past an established stream gaging station during a designated interval--such as April to July 10. This is followed by a statement that gives the forecast in terms of the percent of normal. The various state and federal agencies in the western states designated the 20-year average as the base or normal period. Every five years, the average is updated. In 1987 a 25-year average was designated and by 1992 a 30-year average will be used.

(b) Low-flow forecasts are made which predict levels and date of the levels of the stream. This indicates how long water will last and adequacy of late-season supply, if any is available.

Part 690 - Use of Water Supply Forecasts

SUBPART B - USE OF FORECAST DATA

CO690.20 Water requirements versus available supply.

(a) The Estimated Monthly Normal Consumptive Use and Net Irrigation Water Requirement charts were developed for each crop in the areas served by this guide. The data include effective precipitation, length of crop growing season, etc.

(b) The following example illustrates how these data may be used with cooperators in conjunction with water supply forecasts. Assume that a farm contains 160 irrigated acres. The estimated irrigation water requirements by months for crops grown in the area are shown. Losses in water transmission and application may add 50 percent or more to these irrigation requirements, depending upon the efficiencies of the irrigation methods and farm distribution systems.

(c) The estimated water requirements for the various crops in a particular climatic area may be as follows:

Crop	Total Growing Season Water Requirements (Inches)	Average Effective Rainfall During Growing Season (Inches)	Net Irrigation Water Required (Inches)
Alfalfa Hay	35.04	3.08	31.96
Improved Pasture	30.99	3.08	27.91
Spring Grain	20.28	2.76	17.52
Silage Corn	25.26	2.25	23.01

(d) An example of normal crop plantings on this farm are as follows:

Crop	Acres	Net Irrigation Water Required (Inches)	Net Total Requirements (Ac-ft)	Field Efficiency (%)	Gross Field Application (Ac-ft)	Gross* Farm Application (Ac-ft)
Alfalfa Hay	60	31.96	159.8	60	266.3	279.6
Improved Pasture	40	27.91	93.0	50	186.0	195.3
Spring Grain	20	17.52	29.2	50	58.4	61.3
Silage Corn	40	23.01	76.7	60	127.8	134.2
TOTALS	160				638.5	670.4

*The on-farm transmission system water losses were estimated at 5%. Actual farm transmission losses may vary.

C0690.20(e)

(e) If the forecast and records of the irrigation company indicate that 671 acre-feet can be delivered as required throughout the growing season, adequate water is assured for all crops. If a lesser amount of water is predicted, the farmer will have to make some adjustments as to the most economical acreage on which to apply the available water.

(f) Reference should be made to cost and return information for various crops to help determine highest returns. Use information developed locally or in similar areas, and revised to fit particular situations.

(g) Assume that the allotment of water that can be delivered to the farm throughout the growing season will be 460 acre-feet instead of the 671 acre-feet normally required. If five percent loss in the farm distribution system is estimated, the amount of irrigation water available for the various field crops will be 437 acre-feet. The farmer has several alternatives in determining the cropping pattern and must select those that will fit the particular situations. Examples of these alternatives follow:

(1) Fully irrigate normal acreage of alfalfa hay, and the balance on fully-irrigated pasture to the extent water is available:

Crop	Acres	Total Net Requirements (Ac-Ft)	Field Efficiency (%)	Gross Field Application (Ac-Ft)
Alfalfa Hay	60	159.8	60	266.3
Pasture	36.7	85.4	50	170.7
Idle	63.3	0	0	0
Totals	160			437.0

(2) Another alternative is to fully irrigate the normal acreage of spring grain, pasture, and irrigate alfalfa hay for the first two cuttings only:

Crop	Acres	Net Irrigation Water Required (inches)	Net Total Requirements (Ac-Ft)	Field Efficiency (%)	Gross Field Application (Ac-Ft)
Alfalfa Hay (Jan-July)	60	25.30 1/	126.50	60	210.8
Pasture	26	27.91	60.5	50	121.0
Grain	53	11.82	52.2	50	104.4
Idle	21	0	0	0	0
TOTALS	160				436.2

1/ Determine accumulated net irrigation water requirement from monthly data, part 683.

(3) Assume, as is quite often the case, that the irrigation water will be available only during the early months of the growing season due to a lack of suitable storage. For these conditions, an alternative use of the irrigation water would be as follows: Irrigate alfalfa hay for the first two cuttings; irrigate the pasture during April through July, and use the balance of the water on spring grain.

Crop	Acres	Net Irrigation Water Required (inches)	Net Total Requirements (Ac-Ft)	Field Efficiency (%)	Gross Field Application (Ac-Ft)
Alfalfa Hay (2nd cutting)	60	25.30 1/	126.50	60	210.8
Pasture (April-July)	40	21.10 1/	70.33	50	140.7
Grain	43	11.82	42.36	50	84.7
Idle	17	0	0	0	0
TOTALS	160				436.2

1/ Determine accumulated net irrigation water requirement from monthly data Part 683.